CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab
University of Rochester

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Project Objectives

The CAPTAIN MINERvA project seeks to provide measurements of neutrino interactions on argon nuclei, from the CAPTAIN LAr TPC, and direct comparisons to interactions on carbon from the MINERvA scintillator detector. These measurements in Fermilab's NuMI neutrino beam are a unique opportunity to learn about the high energy neutrino reactions on argon relevant to DUNE before DUNE's near detector is constructed, and the high precision comparison to interactions on carbon provides a stringent test of models of nuclear modifications of neutrino reactions.

Realization of CAPTAIN-MINERvA will require design and procurement of a cryogenic system that can safely be operated in the underground environment of the Fermilab NuMI near detector hall, construction of the CAPTAIN TPC, commissioning of the CAPTAIN detector on the surface, and installation, commissioning and operation of the CAPTAIN detector in the MINOS underground hall upstream of MINERvA, and integration of CAPTAIN and MINERvA's data handling and analysis software into a joint framework. The model for this work brings together a team of University-based technical and engineering staff to supplement the available cryogenic experts at Fermilab. Continuity with the Los Alamos National Lab (LANL) LDRD project that constructed the vast majority of CAPTAIN will be assured by engaging experts at LANL in the design and commissioning phases.

A technically limited schedule will allow operation of CAPTAIN MINERvA in 2018 with first physics results possible after an exposure of a year of the NuMI beam at design intensity.

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University of Rochester
DOE Intermediate Neutrino Research Program

Title: CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab

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Project Narrative

1 Introduction

It is well known that neutrinos propagate as a superposition of mass eigenstates and interact as flavor eigenstates, resulting in the phenomena of neutrino oscillations. Because the neutrino oscillation probability is energy-dependent, reconstruction of the incoming neutrino energy is critical. Experiments that study neutrino oscillations must reconstruct the neutrino energy based only on the final state particles. Therefore, precision measurements of neutrino cross sections and nuclear effects are needed in order to have a complete understanding of neutrino oscillations. Fermilab will host the Long-Baseline Neutrino Facility (LBNF), which will provide a high-power, wide-band muon neutrino beam for DUNE, the Deep Underground Neutrino Experiment [1]. DUNE will use two detectors; a near detector will be located at Fermilab just downstream of the beamline, and a far detector will be located in South Dakota, at a baseline of 1300 km. At that baseline, the first oscillation maximum occurs in the neutrino energy range from 1.5 to 5 GeV, and most of the electron neutrino appearance signal will be in this energy range. DUNE has proposed to use a liquid argon time projection chamber (TPC) for the far detector, and therefore measurements of neutrino-argon interactions in this energy range are crucial for the success of the long-baseline program. The CAPTAIN-MINERνA experiment is designed to address this issue. This proposal describes our intent to install CAPTAIN, a small liquid argon TPC, in front of the MINERνA detector and use the combined data set to study neutrino-argon interactions and liquid argon event reconstruction in the few-GeV neutrino energy range. CAPTAIN-MINERνA will study the nature of the neutrino-nucleus interaction, one of the stated scientific topics of interest for this FOA, and will be able to produce results within five years.

1.1 Detectors and Beam

The MINERνA experiment [2] is currently taking data in the NuMI beamline, a broadband muon neutrino beam at Fermilab with an energy range spanning 3-8 GeV.

This energy range is ideal in that it covers the first oscillation maximum for DUNE and can provide access to both elastic and inelastic processes. The MINERνA detector consists of a series of nuclear targets followed by a fine-grained scintillator tracking region surrounded by electromagnetic and hadronic calorimeters. MINERνA is located in an underground hall upstream of the the magnetized MINOS near detector (ND), which serves as a downstream muon spectrometer. MINERνA's dataset includes interactions on a variety of nuclei ranging from helium to lead. The high intensity of the beam means that with the planned neutrino and antineutrino beam exposure, MINERνA will collect several million neutrino charged current (CC) interactions and expects to have the statistics to measure cross section ratios between graphite, iron, lead and the plastic scintillator from intermediate to high $x_{Bjorken}$ at the few percent level. The fine granularity of the MINERνA detector can also provide cross section ratios for individual neutrino interaction channels, such as coherent and inclusive pion production and quasi-elastic scattering.

MINERνA's first physics publications were high statistics measurements of the quasi-elastic neutrino interaction, for both neutrinos [3] and antineutrinos [4]. Another milestone was reached when MINERνA released its measurements of cross section ratios between iron and scintillator, and lead and scintillator [5]. The disagreement between the MINERνA data and the prediction indicates that the field is not modeling the A-dependence of the quasi-elastic and resonance production processes, which are both critical processes for oscillation experiments.

MINERνA has published an additional four articles on cross sections on plastic and is working to extend its analyses on other final states and to the nuclear target region. Because of the inherent uncertainties on the prediction of the NuMI flux, the best constraints on models of neutrino interactions and nuclear effects come from ratio measurements between different nuclei, where the flux uncertainties cancel. Even at the current uncertainties MINERνA has already been able to improve models of neutrino interactions used by the oscillation experiment T2K. MINERνA also mounted a successful test beam program to determine the response of a detector prototype to a well-understood beam of pions in the 400 MeV to few-GeV region.

CAPTAIN (Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos) is a liquid argon TPC currently being built at Los Alamos National Laboratory (LANL) [6]. The CAPTAIN program consists of a prototype detector, Mini-CAPTAIN, and the full CAPTAIN detector. The CAPTAIN detector is a portable and evacuable cryostat that can hold 7700 liters of liquid argon. The cryostat is an ASME Section VIII, Division 1 U stamped vessel, making operation at Fermilab straightforward. The outer shell of the cryostat is 107.5 inches in diameter, and it is 115 inches tall. The active volume of liquid argon will be five tons. The argon

must stay in the form of a stable liquid and must remain minimally contaminated by impurities such as oxygen and water to prevent the loss of drifting electrons to these electronegative molecules. The argon must also stay sufficiently free of contaminants such as nitrogen to avoid absorption of the scintillation light. The CAPTAIN liquid argon delivery and purification design is based on experiences of the MicroBooNE experiment [7, 8] and the Liquid Argon Purity Demonstration (LAPD) [9], both based at Fermilab. The CAPTAIN TPC consists of a field cage in a hexagonal shape with a 2 m diameter and a vertical upward drift length between the anode and cathode of 100 cm. There are three active wire planes: the U, V, and collection (anode) plane. All wire planes have 75 μm diameter copper beryllium wire spaced 3 mm apart, and the plane separation is 3.125 mm. Each wire plane has 667 wires. The U and V planes detect the induced signal when the electron passes through the wires. The U and V wires are oriented ± 60 degrees with respect to the anode wires. The anode wires measure the coordinate in direction of the track, and U and V are orthogonal to the track. The third coordinate is determined by the drift time to the anode plane. The electronic components for the TPC are identical to those of the MicroBooNE experiment at Fermilab [7, 8]. CAPTAIN will be equipped with a photon detection system to observe scintillation light produced inside the liquid argon. A laser calibration will be employed to monitor the electron lifetime and drift velocity, as well as measure the electric field in-situ. The CAPTAIN electronics, field cage, and cryostat are all in hand, and wiring of the TPC will begin soon. The CAPTAIN purification system is with the vendor, and is expected to be delivered in Fall 2015.

The Mini-CAPTAIN detector is a smaller liquid argon TPC inside a 1500 liter cryostat. The Mini-CAPTAIN TPC is also hexagonally-shaped with a 30 cm height and 1 m diameter with the same number of planes, pitch, and wire spacing as the CAPTAIN detector. At the present time, the Mini-CAPTAIN detector is being commissioned at LANL. Mini-CAPTAIN has been successfully filled with liquid argon and cooled, and the electronics, DAQ, purification system, and laser calibration system are all being tested. Mini-CAPTAIN will run in a neutron beam at the Los Alamos Neutron Science Center for approximately one week during the next beam cycle in January 2016. Figure 1 shows the first demonstration of an ionization track from a laser calibration system in the Mini-CAPTAIN detector, announced in August 2015.

The CAPTAIN-MINERνA program will make use of the NuMI beamline, which produces a high intensity on-axis neutrino beam peaked at about 6 GeV. The beam is created when 120 GeV protons strike a graphite target to create pions, and those pions are then focused with a two-horn system and sent to a 675 m long decay pipe. The polarity of the horns can be either positive or negative, resulting in a 97% (94%)

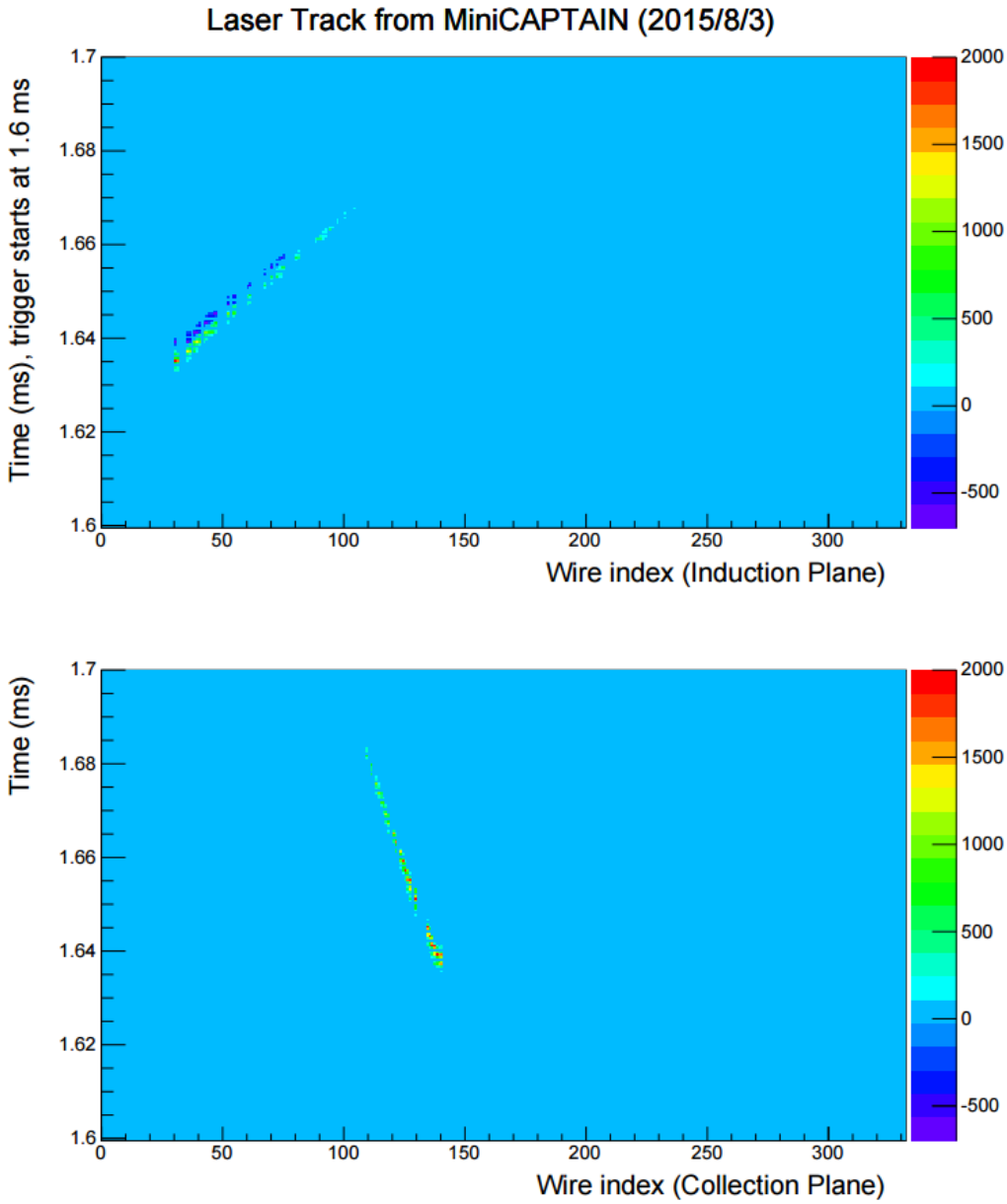

Figure 1: An ionization track from the laser calibration system in Mini-CAPTAIN. The data were collected on August 3, 2015 and were created with a high-intensity UV laser pulse traversing the TPC. The detector was running with one collection plane and one induction plane. The color represents ADC value.

pure beam of neutrinos (antineutrinos) at the peak neutrino energy. The operation of changing from one polarity to the other takes less than one 8-hour shift, but is not expected to be changed frequently given the plans of other experiments using the beamline.

The NuMI beam is currently in use by the MINERνA, MINOS+, and NOνA experiments. At the time of this writing the NuMI medium-energy beam is operating at 450 kW and is expected to provide some 6×10^{20} protons-on-target (POT) per year by 2016. The intensity of this beam means that an adequate sample of events on liquid argon could be collected with only a year of running in each of the neutrino and antineutrino configurations.

1.2 CAPTAIN-MINERνA

CAPTAIN-MINERνA will be the only experiment making high-statistics neutrino-argon interaction measurements in the energy range of a few GeV before DUNE. Results on neutrino-argon interactions (for example [10]) have been released from ArgoNeuT, a 170 liter (0.25 ton active volume) liquid argon TPC that took data in the NuMI low-energy beam configuration. With a fiducial mass approximately 20 times larger than that of ArgoNeuT, CAPTAIN will collect significantly more events and have better containment of the final state particles. MicroBooNE [7, 8], a 170-ton liquid argon TPC ($\sim$100-ton active volume) which recently completed construction at Fermilab, will study neutrino interactions on argon in the Booster Neutrino Beam (BNB) at Fermilab. The BNB has a peak neutrino energy $\mathcal{O}$(1 GeV), consistent with the energy range of the second oscillation maximum for a baseline of 1300 km. Thus measurements made by CAPTAIN in the NuMI beam are complementary to the low-energy neutrino measurements that will be made by MicroBooNE in the BNB.

Figure 2 compares the neutrino flux from the medium-energy NuMI beam at the proposed location of CAPTAIN-MINERνA, the flux from the BNB at the location of MiniBooNE, and the proposed flux for DUNE at the DUNE far detector. The NuMI beam overlaps the entire neutrino energy range for DUNE, though the NuMI beam peaks at a higher neutrino energy. The fact that the CAPTAIN-MINERνA experiment will actually have a different incoming neutrino spectrum than the DUNE far detector is also an advantage in that it will allow a cross check on the modeling of the convolution of energy-dependent cross sections and energy-dependent nuclear effects in neutrino-argon interactions made with the DUNE near detector. Figure 2 also shows the cross section for CC neutrino-argon interactions, which are dominated by pion production and Deep Inelastic Scattering (DIS) in the energy range relevant for DUNE. Simulations indicate that approximately 68% of all CC neutrino inter-

actions in CAPTAIN-MINERνA will have at least one pion in the final state; in MicroBooNE, approximately 60% of the interactions will be quasi-elastic. Therefore CAPTAIN-MINERνA will have the unique ability to study event reconstruction for a large sample of neutrino events with significant particle multiplicities.

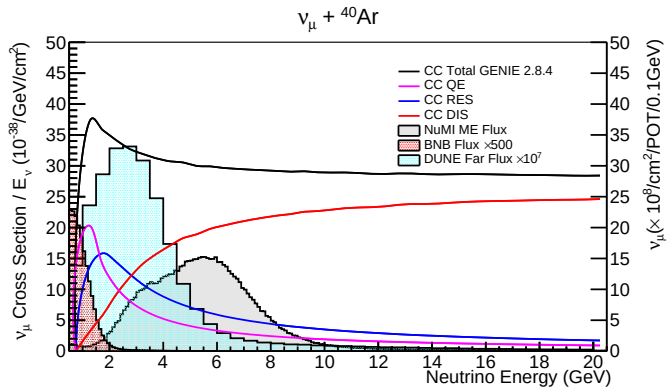

Figure 2: Unoscillated ν_μ DUNE far flux, BNB flux at MiniBooNE, medium-energy NuMI flux at the proposed location of CAPTAIN-MINERνA, and GENIE [11] cross sections on ^{40}Ar.

CAPTAIN will be placed upstream of MINERνA and serve as the vertex detector. Liquid argon TPCs provide excellent position resolution, energy resolution, and particle identification, enabling precision reconstruction of complex interaction topologies. Combining CAPTAIN and MINERνA is beneficial because particles exiting CAPTAIN, most importantly forward-going muons, can be tracked and their energy measured in MINERνA and/or the MINOS ND, resulting in a far better estimate of the incoming neutrino energy than could be achieved with CAPTAIN alone. In addition, by making measurements of cross section ratios, namely argon to hydrocarbon in the scintillator, stringent tests of the nuclear effect models can be made, since these cross section ratios are not hampered by large flux uncertainties. Another advantage of integrating CAPTAIN into MINERνA is that the combined CAPTAIN-MINERνA detector could serve as a model for a DUNE near detector system. The reference design for the DUNE near detector is a fine-grained tracker detector designed to make precision measurements of the neutrino flux, cross sections, and signal and background rates. One enhancement to the reference design under consideration is the addition of a liquid argon TPC upstream of the fine-grained tracker to be used for a relative measurement with identical near and far detector technology.

The simplest way to integrate the CAPTAIN detector into MINERνA is to replace

MINERνA's existing liquid helium target with the CAPTAIN detector, and this is our default plan. Depending on the timing of the run, it might also be possible to remove MINERνA's nuclear targets and some of the scintillator tracking planes to place CAPTAIN closer to the MINOS ND for better muon acceptance. This option would only be considered once MINERνA has collected adequate statistics in its solid nuclear targets. Figure 3 is a drawing showing the relative sizes of the detectors and a possible location for CAPTAIN in front of MINERνA, assuming the nuclear targets have been removed.

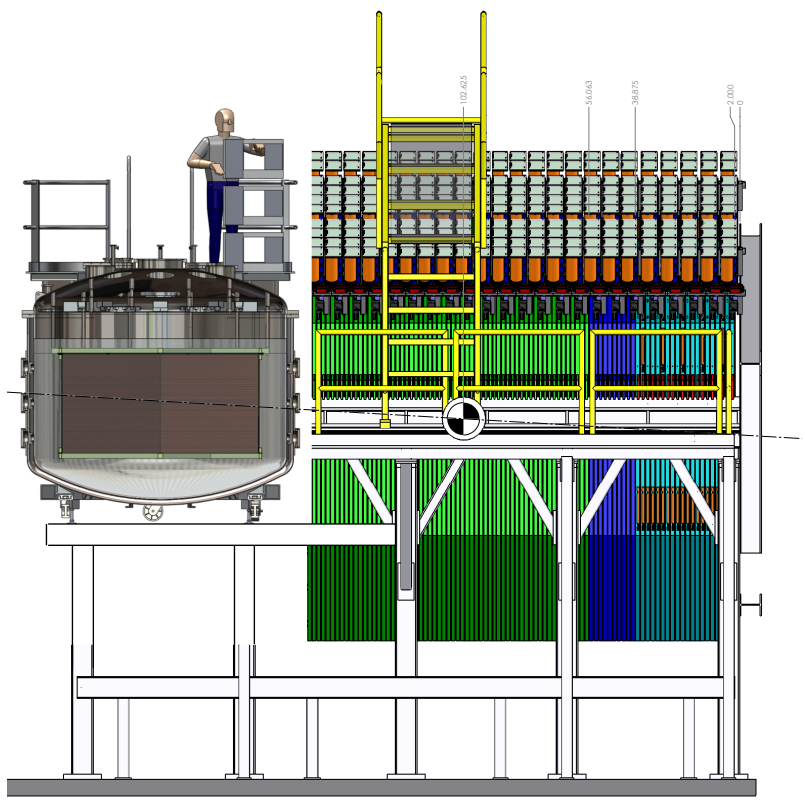

Figure 3: Location of the CAPTAIN detector in front of the MINERνA detector. The neutrino beam travels from left to right at an angle of 58 mrad to the horizontal.

We performed simulations of neutrino interactions on liquid argon with the CAPTAIN detector geometry placed upstream of the MINERνA detector with the on-axis medium-energy (ME) NuMI flux. The simulations predict 12.5M ν_μ CC interactions within the TPC fiducial volume for an exposure of 6×10^{20} POT. To study the ac-

ceptance of ν_μ CC events in MINERνA and the MINOS ND, neutrino interactions were generated within the TPC fiducial volume using GENIE 2.8.4 [11]. MINERνA's detector response is simulated with a tuned GEANT4-based [12, 13] program. The MINOS ND is located 2 m downstream of the MINERνA detector. The magnetized MINOS ND can provide measurements of muon momentum and the sign of the muon charge for events where the muon reaches the MINOS ND. This is particularly important for an antineutrino flux configuration to avoid wrong sign contamination. If a muon is reconstructed in the MINOS ND, the muon momentum is measured by the MINOS ND from the track curvature or its range depending on whether the muon stops in the detector. A detailed study by MINERνA shows that the total momentum uncertainty for muons is 2-3% for the curvature-based measurement relative to the range-based measurement [2]. For events where the muon does not reach the MINOS ND, the MINERνA detector can provide a reconstructed muon track, but not the sign of the muon charge. Figure 4 (left) shows the incoming neutrino energy distribution for ν_μ CC interactions in the CAPTAIN TPC in the ME NuMI configuration. On the right, the muon angle with respect to the neutrino beam direction is shown for all CC events, CC events in which the muon reaches the MINOS ND, and CC events in which the muon reaches only the MINERνA detector.

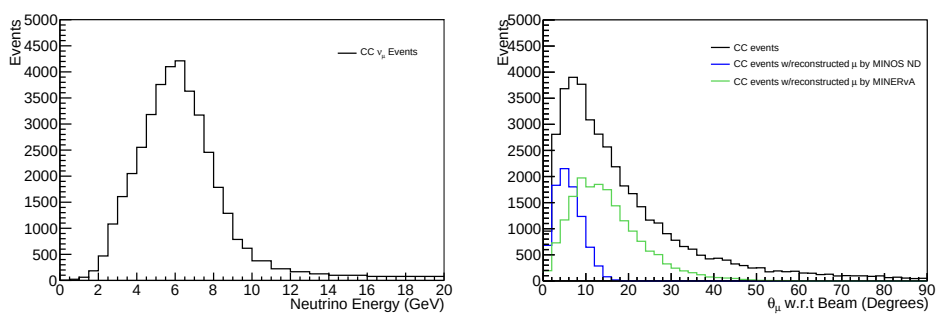

Figure 4: Left: Incoming neutrino energy for ν_μ CC interactions in the CAPTAIN TPC in the NuMI ME flux configuration. Right: Muon angle with respect to the neutrino beam direction for all CC events (black), CC events with a muon reconstructed by the MINOS ND (blue), and CC events with a muon reconstructed by MINERνA (green).

By considering muons that reach MINERνA or the MINOS ND, the overall muon reconstruction efficiency for ν_μ CC events is 64%. (23% of CC interactions have a muon reconstructed by MINOS, and 41% of CC interactions have a muon reconstructed by MINERνA.) For the remaining CC interactions, CAPTAIN will have

some ability to tag muons that miss MINERνA or MINOS by looking for MIP-like tracks.

Reconstructing the incoming neutrino energy is crucial in order to measure oscillation parameters. One of the key factors in neutrino energy reconstruction is detector containment. We define an event as fully contained if the neutrino interaction vertex is inside of the TPC fiducial volume and all primary particles have an end point inside of the TPC fiducial volume. Particles excluded from this requirement include muons, neutrons and neutrinos. Approximately 20% of ν_μ CC interactions will have all the hadronic energy contained within the TPC. Given the muon reconstruction efficiency of 64%, roughly 10-15% of ν_μ CC events will have a muon reconstructed by MINERνA or MINOS *and* all the hadronic energy contained within the TPC fiducial volume. This subset of events will have the best reconstructed energy resolution. By placing the CAPTAIN detector upstream of the MINERνA detector, MINERνA can be used as a calorimeter for events where final state particles exit CAPTAIN and reach MINERνA.

Table 1 shows the expected event rate for CCQE-like events ($\nu_\mu + ^{40}Ar \rightarrow \mu^- + Np$ and no mesons, N can be any number of protons), CC $1\pi^\pm$ ($\nu_\mu + ^{40}Ar \rightarrow \mu^- + \pi^\pm + X$) and CC $1\pi^0$ ($\nu_\mu +^{40} Ar \rightarrow \mu^- + \pi^0 + X$) assuming a 6×10^{20} POT exposure. The CAPTAIN detector is of a comparable fiducial mass to that of the inner tracking region of the MINERνA detector, so the statistical uncertainties for both samples will be comparable.

	Events w/ reco μ	Events w/ reco μ and charge
CCQE-like	916k	784k
CC$1\pi^\pm$	1953k	966k
CC$1\pi^0$	1553k	597k

Table 1: Event rates for all CC events with a reconstructed muon and and for the subset of events with reconstructed tracks in which the charge sign is also reconstructed for an exposure of 6×10^{20} POT.

CAPTAIN-MINERνA was granted Stage 1 approval by the Fermilab Director in July 2015. We expect that the CAPTAIN-MINERνA program can be executed in five years which includes at least two years of data-taking. Ideally, CAPTAIN-MINERνA would acquire at least 6×10^{20} POT in neutrino mode and 6×10^{20} POT in antineutrino mode.

2 Project Objectives

Realization of CAPTAIN-MINERνA requires the design and procurement of a cryogenic system that can safely be operated in the MINOS underground hall, commissioning of the full-sized CAPTAIN detector on the surface, and installation, commissioning and operation of the CAPTAIN detector in the MINOS underground hall upstream of MINERνA.

The project is divided into several different sub-projects, which are listed in a work breakdown structure in Table 2.

WBS	Task	Begin	End
1.1	Project Administration	3/1/16	7/16/18
1.2	Cavern Preparation Work at FNAL	3/1/16	3/31/16
1.3	TPC Assembly	7/1/16	12/15/16
1.4	CAPTAIN Commissioning Preparation - Surface	3/1/16	9/19/16
1.5	Assembly of CAPTAIN- Surface	1/3/17	7/23/18
1.6	CAPTAIN Commissioning - Surface	5/29/17	3/15/18
1.7	Engineering Design for Underground	3/1/16	9/20/16
1.8	Drafting effort for Underground Work	3/1/16	11/21/16
1.9	Fabrication and Installation Underground	4/26/16	8/30/18
1.10	Computing	9/1/16	11/23/16

Table 2: Work Breakdown Structure of the CAPTAIN-MINERνA project and the start and end dates of the different level 2 sub-projects, in a technically driven schedule.

2.1 Cryosystem design and drafting

CAPTAIN will be cooled by cryocoolers underground, rather than by running a heat exchanger with a liquid nitrogen supply, as is done in MicroBooNE. Using a cryocooler underground will reduce the labor costs associated with installing pipes that run the length of the shaft, and also will reduce the oxygen deficiency hazard (ODH) risks because the total volume of cryogens underground will be much smaller. The heat load for CAPTAIN is calculated to be 700 W, and so CAPTAIN could be easily serviced by two 600-W units. For reference, the Mini-CAPTAIN measured heat load is 230 W, which is very close to the expected rate.

The cryogenic system, including the cryogenic and gas lines, vent stack, and oxygen and water monitors, must be designed, drafted, and fabricated before CAP-

TAIN's assembly at Fermilab. The cryostat is an ASME Section VIII, Division 1 U stamped vessel, which will greatly simplify the design and review of the system.

A technically driven schedule for the engineering design will require approximately seven months, and can start as early as funding is available. The designs will be reviewed both technically and for safety considerations by Fermilab engineers and safety officers. The drafting can progress in parallel with the engineering effort, although the solid modeling of the piping and the final fabrication drawings will extend the drafting tasks an additional two months past the engineering tasks.

2.2 Assembly and commissioning of the CAPTAIN detector above ground

Before CAPTAIN is operated underground as part of CAPTAIN-MINERνA, the detector will be assembled and tested above ground at Fermilab. At LANL, the TPC will be assembled including the support frame assembly, wire plan assembly, field cage assembly, wire stringing, and cathode plane fabrication. The purification system will also be commissioned. Subsequently, the CAPTAIN detector components and services will be packed at LANL and shipped to Fermilab. At Fermilab, the components will be inspected and tested upon arrival. A surface hall will be prepared for CAPTAIN assembly and commissioning.

The assembly and commissioning process is carried out methodically with thorough testing at each step. Initially, the TPC will reside in a temporary clean area. When the cryostat and cryogenics are in place and when all required systems are attached to the TPC and tested, the TPC assembly will be lowered into the cryostat for further testing. Subsequently, the cryostat will be sealed and the system will undergo further testing. Finally, liquid argon will be introduced and purified, and commissioning will commence.

The outline of activities in the surface commissioning hall at Fermilab is as follows:

- TPC (wire-planes and field cage assembly) is mounted to the cryostat lid.
- Field cage continuity retested.
- Front-end electronics are mounted to the TPC and tested with the DAQ.
- HV feed-through is mounted to cryostat lid and continuity tested.
- In parallel, cryogenic and gas systems are assembled.
- Photon detection system is mounted to the TPC and tested.

- Laser system is mounted to the TPC and cryostat lid, aligned, and tested.
- TPC assembly (now including HV feed-through, photon detection system and laser calibration system) is lifted, translated and lowered into the cryostat. The assembly is tested in place, including HV.
- Cryostat is sealed with indium and leak tested.
- Cryo and gas line connections are made and leak tested. Electronics and instrumentation lines are readied.
- Liquid argon is filled; DAQ and HV are tested.
- Liquid argon is recirculated and purified.
- Commissioning with cosmic-rays and laser calibration system is carried out.

2.3 Preparation of the MINOS hall

The largest safety issue associated with CAPTAIN-MINERνA is the fact that this volume of liquid argon represents a significant oxygen deficiency hazard (ODH) if for some reason the vessel were to leak catastrophically. Because of the relative density of argon to oxygen, the oxygen in the underground cavern would relatively quickly be displaced.

The solutions to mitigate this hazard are already being examined in the context of the DUNE liquid argon operations and involve careful containment and then venting of any potentially spilled argon. There is currently a 19-inch diameter shaft in the downstream end of the MINOS underground hall; that shaft could be part of the venting system in addition to the upstream shaft. Nevertheless it is likely that people working underground would need to bring supplies of oxygen with them as a precaution, and the area would no longer be classified as an ODH class 0 enclosure. These restrictions are not unprecedented either at Fermilab or at other laboratories worldwide.

The CAPTAIN detector will fit in front of the MINERνA detector and be supported from below to be centered on the neutrino beam. MINERνA's cryogenic helium target will be dismantled and removed to make room for CAPTAIN, but everything else would stay as it is currently configured in the hall. A stand to support CAPTAIN will need to be designed and fabricated.

In addition, the auxiliary purification system, electronics, and controls systems will also need to fit in a space near the CAPTAIN detector. The commissioning on

the surface will allow for a more convenient test of the logistics of these additional components before installation underground.

The preparations for the underground installation with MINERνA, if they simply involved removing MINERνA's helium target, could start approximately one month before installation. The resources needed for these preparations are not requested in this proposal, but would involve a four-person crew of Fermilab mechanical technicians.

2.4 Installation and commissioning of the CAPTAIN detector underground

CAPTAIN will be disassembled on the surface in order to safely lower all of its systems into the MINOS underground hall. The MINOS shaft through which all equipment must pass to be installed underground is roughly half of a cylinder that is 22 feet in diameter. The 15-ton capacity crane that operates in the shaft is adequate to lower the CAPTAIN vessel, which when empty weighs 5 tons. A cart will be built to accept the vessel when it reaches the lower level, and the cart can be pulled using the same fork-truck by which the MINOS and MINERνA detectors were installed.

Underground assembly and commissioning will proceed as it did on the surface, including the deployment of the same clean area required for assembly and testing of the TPC and all systems and services (e.g. photon detection system). With the experience on the surface, the assembly and commissioning steps will be relatively straightforward.

2.5 Safety and operations issues

Safe operation of detectors that use large masses of cryogenic fluids and high voltage has been of paramount concern as the plan presented here was developed. The Mini-CAPTAIN commissioning experience at LANL has played a crucial role in the development of this proposal. Electrical safety reviews are required for every operating experiment at Fermilab, and will be conducted for surface and underground operations. Further, surface and underground cryogenic operations require a detailed oxygen-deficiency hazard (ODH) analysis and mitigation strategy. Finally, remote operation of the CAPTAIN detector including its cryogenic systems is necessary and will enable remote shifts for CAPTAIN-MINERνA.

The CAPTAIN cryogenic system is based on MicroBooNE and other systems in operation at Fermilab and was even fabricated by the same vendor. We will employ the same cryogenic control system hardware as MicroBooNE with the exception of

the use of cryocoolers rather than a large supply of liquid nitrogen. As stated before, this will limit the amount of cryogen brought into the underground hall.

2.6 Computing

2.6.1 Joint reconstruction

CAPTAIN uses a software framework based on the T2K ND280 software. The framework is based on the ROOT analysis framework [14] and is designed to be modular with as few outside dependencies as possible. MINERνA uses the Gaudi software framework [15], which is used by several particle physics experiments. Because CAPTAIN and MINERνA are operating under independent software frameworks, joint reconstruction will be performed using separately reconstructed objects from each detector. This is similar to the situation with MINERνA and the MINOS ND, where the MINERνA and MINOS track matching is done with tracks that have been reconstructed independently in each detector. The T2K ND280 also operates in a similar manner in which reconstructed tracks from independent sub-detectors (P0D, TPC, FGD, ECal) are combined into a single global track fit. A demonstration of joint reconstruction between CAPTAIN and MINERνA for simulated CAPTAIN-MINERνA interactions will be performed before data-taking commences.

2.6.2 Framework transition

The Gaudi software framework used by MINERνA is not supported by the Fermilab Scientific Computing Division. Migrating the existing MINERνA software framework into the art framework, which is supported by Fermilab and used by other Fermilab experiments such as MicroBooNE and DUNE, would be very valuable. It would make long-term support for the MINERνA code much simpler and would make it more straightforward to take advantage of developments at Fermilab that are targeted at art. Furthermore, if the CAPTAIN framework was also migrated to art at some point, it would make it simpler for analyzers in CAPTAIN-MINERνA to share code and for developers to contribute to both code bases. Support for designing this software framework transition for MINERνA is included in this proposal.

CAPTAIN's DAQ software is based on artdaq, a data acquisition toolkit for particle physics experiments supported by the Fermilab, and is similar, though not identical, to the DAQ software used by MicroBooNE. MINERνA's DAQ software and electronics [16] is based on a JLAB program called ET (Event Transfer), a core package of the CODA suite [17]. If MINERνA's offline framework is changed, shifting the MINERνA DAQ to use artdaq might also be considered. Transitioning to artdaq

for MINERνA could improve the overall long-term support and would provide the opportunity to integrate the monitoring software for CAPTAIN and MINERνA.

2.6.3 Data storage and processing

The computing needs for the CAPTAIN TPC in the CAPTAIN-MINERνA experiment have been evaluated based on the expected NuMI beam intensity and assuming the data is collected using a minimum bias beam trigger with the full TPC and photosensor data for each beam spill recorded without zero suppression. We have also included the estimated resources needed to calibrate the detector as well as produce a sample of simulated neutrino interactions for the CAPTAIN-MINERνA exposure to the NuMI beam. The estimated data storage use for CAPTAIN is 784 TB per year, including data and simulations. The total expected processing time is 6104 cpu-days per year, which includes three reconstruction passes per year for CAPTAIN data and simulated data.

For FY2016, MINERνA estimates a total processing usage of approximately 1.2×10^6 cpu-days and data storage usage of approximately 2 PB, and we expect MINERνA will have similar storage and processing requirements per year in the CAPTAIN-MINERνA era. Note that MINERνA's processing usage includes processing for reconstruction and analysis, while CAPTAIN's estimates include only reconstruction. Nevertheless, the data storage and processing requirements for CAPTAIN-MINERνA are a modest increase over MINERνA's current usage, and Fermilab has adequate resources to fulfill the requirements.

2.7 CAPTAIN-MINERνA results

Some of the first major results to come out of CAPTAIN-MINERνA will include the total muon neutrino and muon antineutrino CC cross sections on argon, ratios of CC cross sections on argon to plastic scintillator, and demonstration of electron neutrino detection and identification in liquid argon (using the small electron neutrino component of the NuMI beam). Examples of further studies that will be possible with the CAPTAIN-MINERνA data set include analysis of CC coherent scattering, for which the cross section will be larger in argon than carbon due to the larger A. The exact A-dependence for single charged pion production via CC coherent scattering can be studied, and other CC coherent scattering processes that are not well-measured to date will become accessible. Final state interactions (FSI) will be a larger effect in liquid argon than in MINERνA's scintillator target, and the FSI models currently in use can be improved based on CAPTAIN-MINERνA's data set. Other studies

will be enabled due to the fine spatial resolution in CAPTAIN, such as the study of two-body CC production of hyperons in antineutrino scattering.

The cross section measurements will benefit from the expertise and analysis infrastructure already in place for such measurements from the MINERνA collaboration. The results will be made available in a timely manner to the GENIE collaboration, the DUNE collaboration, and other liquid argon and neutrino experiments. Operations and data analysis will involve many graduate students and postdocs, and we expect that many theses will be written based on the CAPTAIN-MINERνA data set.

3 Project Organization

All technical aspects of the project will be managed through the Technical Director Christopher Mauger, who, together with Principal Investigator Kevin McFarland, will appoint managers of the various components. These managers will report weekly to Mauger and McFarland. Financial tracking of this project will be done by the University of Rochester, and the progress on this project will be reviewed regularly by Fermilab through the Project Management Group process.

4 Collaboration Governance

The physics goals described in this proposal are of interest to both the current CAPTAIN and MINERνA collaborations, and the effort needed to achieve these goals is larger than either current collaboration could supply. Therefore we plan for members of each of the two current collaborations to join together to form a new collaboration, the CAPTAIN-MINERνA collaboration. This proposal is presented on behalf of the current members of both collaborations who expect to contribute to the CAPTAIN-MINERνA experiment, including 61 CAPTAIN collaborators from 15 institutions and 66 MINERνA collaborators from 15 institutions, for a total of 127 collaborators from 30 institutions. Additional collaborators from new institutions that are not part of the current CAPTAIN or MINERνA collaborations will be able to join CAPTAIN-MINERνA according to a formal procedure that will be determined by the CAPTAIN-MINERνA collaboration.

Data taken by the MINERνA detector, the MINOS ND, and the CAPTAIN detector during the operation of CAPTAIN-MINERνA will be available to all members of the CAPTAIN-MINERνA collaboration. Simulation, reconstruction, and online

monitoring software from both MINERνA and CAPTAIN will also be shared among all CAPTAIN-MINERνA collaborators.

The surface commissioning of the CAPTAIN detector at Fermilab that is described in this proposal will primarily be the responsibility of the CAPTAIN collaboration. However, MINERνA collaborators that are interested in participating will be welcomed and included as authors on any CAPTAIN publications based on data from the surface commissioning. Once the detector is moved underground at Fermilab, the CAPTAIN-MINERνA collaboration will be responsible for all activities related to operating the CAPTAIN detector in conjunction with the MINERνA detector.

One of the MINERνA co-spokespeople and the CAPTAIN spokesperson or deputy spokesperson will initially lead the CAPTAIN-MINERνA effort. The CAPTAIN-MINERνA collaboration will meet to determine a mechanism to elect co-spokespeople and form an executive committee. We also anticipate having an institutional board that will include all institutions involved in CAPTAIN-MINERνA.

5 Timeline

At the time of this writing, the CAPTAIN vessel, TPC wire frame, electronics, and purification system are located at LANL. In order to complete this program those items must be shipped to Fermilab and assembled for commissioning on the surface, brought underground and placed on a stand that centers the detector on the beam, and then hooked up to support systems for purification, cryogenics, and electronics readout.

During the first year of this proposal, the bulk of the activities funded will be the design and drafting of the cryogenic and controls systems appropriate for underground operations. Once those systems have been designed, procurement of the cryocoolers and associated piping and controls systems can start. During the first year the purification system will be tested and then shipped to Fermilab, along with the other components of the CAPTAIN detector which are currently at LANL. The CAPTAIN detector stand will also be designed this first year, along with the ODH mitigation system, and components procured for fabrication of those items. The above-ground facility for the surface commissioning will need to be cleared and prepared during this first year.

During the second year of this proposal the commissioning above ground can begin, by using (as much as possible) the same cryogenic, ventilation, and controls systems that will be used underground. The tasks and tests involved with commissioning are listed in Section 2.2. Up to two fills with argon above ground have been

budgeted for this second year, and the plan is to commission the laser calibration system above ground during this time.

Some of the preparations for the site underground will need to take place during the Fermilab accelerator shutdowns that occur each summer, in order to minimize MINERνA detector downtime. Once the cryogenic and ventilation systems have been designed, the underground preparation can begin, possibly as early as the 2016 Summer shutdown.

During the third year the helium target will be removed from the front of the MINERνA detector, and depending on the status of the antineutrino data set, MINERνA's upstream nuclear target region may also be removed. The CAPTAIN detector will be moved from the surface commissioning site to the MINOS underground hall, and underground commissioning can take place in the third year. Neutrino data-taking may begin during the third year, and ideally the detector would take one year of neutrino data and one year of antineutrino data.

6 Summary

In summary, current members of the CAPTAIN and MINERνA collaborations propose to form a new collaboration, called CAPTAIN-MINERνA, that will study neutrino-argon interactions in the neutrino energy range relevant for the DUNE long-baseline neutrino oscillation experiment. The five-year program described in this proposal will include design and procurement of a cryogenic system that can safely be operated in the MINOS underground hall, commissioning of the CAPTAIN detector in an above ground location at Fermilab, installation and commissioning of the CAPTAIN detector in the MINOS underground hall upstream of MINERνA, and two years of taking data.

Biographical Sketch of Kevin Scott McFarland

Education and Training

Brown Univ.	Physics	Sc.B.	1989
Univ. of Chicago	Physics	M.Sc.	1991
Univ. of Chicago	Physics	Ph.D.	1994

Research and Professional Experience

Professor of Physics, Univ. of Rochester, 2005-present
Guest Scientist (MINERνA Co-spokesperson), Fermilab, 2009-present
Associate Chair, Department of Physics and Astronomy Univ. of Rochester 2007-2010
Associate Professor of Physics, Univ. of Rochester, 2002-2005
Fellow, American Physical Society, 2005-
Guest Scientist (CDF Offline Coordinator), Fermilab, 2000-2002
Assistant Professor of Physics, Univ. of Rochester, 1998-2002
National Science Foundation Career Award, 2002
Dept. of Energy Outstanding Junior Investigator Award, 1999
Leon M. Lederman Fellow, Fermilab, 1994–1998

Publications (selected from more than 720)

1) B.G. Tice *et al.* [MINERνA Collab.], "Measurement of ratios of muon neutrino charged-current cross sections on C, Fe, and Pb to CH at neutrino energies 2-20 GeV," Phys. Rev. Lett. **112**:231801, (2014).
2) L. Fields *et al.* [MINERνA Collab.], "Measurement of muon neutrino quasi-elastic scattering on a hydrocarbon target at an average neutrino energy of ~3.5 GeV", Phys. Rev. Lett. **111**:022501, (2013).
3) G.A. Fiorentini et al., [MINERνA Collab.], "Measurement of muon neutrino quasi-elastic scattering on a hydrocarbon target at an average neutrino energy of ~3.5 GeV", Phys. Rev. Lett., **111**:022502, (2013).
4) K. Abe *et al.* [T2K Collab.], "Precise measurement of the neutrino mixing parameter theta23 from muon neutrino disappearance in an off-axis beam", Phys. Rev. Lett. 112: 181801, (2014).
5) K. Abe *et al.* [T2K Collab.], "Observation of electron neutrino appearance in a muon neutrino beam", Phys. Rev. Lett.**112**:061802, (2014).
6) M. Day and K.S. McFarland, "Differences in quasi-elastic cross-sections of muon and electron neutrinos", Phys. Rev. D86 (2012) 053003.
7) A. Abulencia *et al.* [CDF Collab.], "A search for top decay into tau, neutrino and quark in top-antitop production", Physics Letters B639, 172 (2006).
8) G.P. Zeller *et al.* [NuTeV Collab.] "A precise determination of electroweak parameters in neutrino-nucleon scattering", Phys. Rev. Lett. 88, 091802 (2002).
9) I. I. Bigi *et al.*, "The potential for neutrino physics at muon colliders and dedicated high current muon storage rings," Phys. Rep. 371, 151 (2002).
10) P. Fisher, B. Kayser, K.S. McFarland, "Neutrino mass and oscillations", Ann. Rev. NS49 481 (1999).

Synergistic Activities

1. Co-spokesperson, MINERvA Collaboration, 2003-present.
2. Leader and PI, PARTICLE project (outreach for high school teachers and students), University of Rochester, 1999-present. http://www.pas.rochester.edu/particle/
3. Member, HEPAP Sub-Panel on Long-Range Planning for US High Energy Physics (Bagger/Barish sub-panel), 2001. Member, HEPAP Sub-Panel on University Grant Program Support, 2006-2007.
4. Co-Leader, CDF Offline Computing. 2000-2002.
5. Leader, CDF Level-3 PC Farm Project, a collaboration at Fermilab between computer scientists and physicists to adapt a scalable commercial PC farm architecture to high-rate, real-time data acquisition and processing applications, 1997-2000.

Collaborators and Other Affiliations

Members of the MINERvA Collaboration at Fermilab (70 physicists)
Members of the T2K Collaboration at J-PARC (450 physicists)
Members of the CDF Collaboration at Fermilab (450 physicists)
Members of the NuTeV Collaboration at Fermilab (35 physicists)
Members of the E799/E773 Collaborations at Fermilab (40 physicists)

Graduate Advisor: Prof. Yau Wah, University of Chicago

Graduate and Postdoctoral Advisees during the last 10 years:

Former Postdoctoral Advisees (8): Dr. Veronique Boisvert (Lecturer, Royal Holloway University London), Dr. Robert Bradford (Associate Scientist, Argonne National Lab), Dr. Gilles deLentdecker (Chercheur Qualifié, Université Libre de Bruxelles), Dr. Aaron Higuera (Res. Assoc., U. of Houston) Dr. Laura Loiacono (industry), Dr. Aaron McGowan (Lecturer, Rochester Institute of Technology), Dr. Gabriel Perdue (Scientist, Fermilab), Dr. Kirsten Tollefson (Associate Professor, Michigan State University), Dr. Anthony Vaiciulis (Scientist, Fair Isaac Corporation)

Current Postdoctoral Advisees (3): Dr. Tomasz Golan (jointly advised with Dr. Gabe Perdue at Fermilab), Dr. Philip Rodrigues, Dr. Daniel Ruterbories

Former Graduate Students (7): Dr. Jesse Chvojka (Analyst, Bauer Consulting), Dr. Melanie Day (Res. Assoc, U. Wisconsin), Dr. Bo-Young Han (Scientist, Korea Atomic Energy Research Institute), Dr. Benjamin Kilminster (Prof. Univ. of Zurich), Dr. Sarah Demers Konezny (Assistant Professor, Yale University), Dr. Jedong Lee (Analyst, Mercator Financial), Dr. Jaewon Park (Res. Assoc., Virginia Polytechnic)

Current Graduate Students (7): Mr. Aaron Bercellie, Mr. Robert Fine, Mr. Jeffrey Kleykamp (secondary adviser) Mr. Konosuke Iwamoto, Mr. Chris Marshall, Mr. Aaron Mislivec, Mr. Jeremy Wolcott (secondary adviser)

Biographical Sketch of Deborah Appel Harris

Education and Training

Univ. of California at Berkeley	Physics	Sc.B.	1989
Univ. of Chicago	Physics	M.Sc.	1992
Univ. of Chicago	Physics	Ph.D.	1994

Research and Professional Experience

Scientist II, Fermi National Accelerator Laboratory, 2010-present
Fellow, American Physical Society, 2015-
MINERνA Co-Spokesperson, 2010-Present
MINERνA Project Manager, 2005-2010
Scientist I, Fermi National Accelerator Laboratory, 2005-2010
Associate Scientist, Fermi National Accelerator Laboratory, 1999-2005
Postdoctoral Research Fellow, University of Rochester, 1994-1999

Publications (selected from more than 100)

1) A. Higuera, A. Mislivec*, et al.* [MINERνA Collab.], "Measurement of Coherent Production of π in Neutrino and Anti-Neutrino Beams on Carbon from E_ν of 1.5 to 20 GeV", Phys. Rev. Lett. **113**: 261802 (2014)
2) B.G. Tice *et al.* [MINERνA Collab.], "Measurement of ratios of muon neutrino charged-current cross sections on C, Fe, and Pb to CH at neutrino energies 2-20 GeV," Phys. Rev. Lett. **112**:231801, (2014)
3) L. Fields *et al.* [MINERνA Collab.], "Measurement of muon neutrino quasi-elastic scattering on a hydrocarbon target at an average neutrino energy of ~3.5 GeV", Phys. Rev. Lett. **111**:022501, (2013)
4) G.A. Fiorentini et al., [MINERνA Collab.], "Measurement of muon neutrino quasi-elastic scattering on a hydrocarbon target at an average neutrino energy of ~3.5 GeV", Phys. Rev. Lett., **111**:022502, (2013)
5) L. Aliaga et al, [MINERνA Collab.] "Design, Calibration and Performance of the MINERνA Detector", Nucl. Inst. and Meth. **A743**:130, (2014)
6) P. Adamson et al., [MINOS Collab.] "Measurement of Neutrino Oscillations with the MINOS Detectors in the NuMI Beam", Phys. Rev. Lett. **101**:131802, (2008).
7) D. G. Michael *et al*., [MINOS Collab.] "Observation of muon neutrino disappearance with the MINOS detectors and the NuMI neutrino beam", Phys. Rev. Lett. **97**:191801, (2006)
8) G.P. Zeller *et al.* [NuTeV Collab.] "A precise determination of electroweak parameters in neutrino-nucleon scattering", Phys. Rev. Lett. **88**: 091802, (2002).
9) J.J. Gomez-Cadenas and D.A. Harris "Physics Opportunities at Neutrino Factories" Ann.Rev.Nucl.Part.Sci. **52**:253, (2002)
10) J.H. Kim, D.A. Harris et al [CCFR Collab] "A Measurement of α_s (Q^2) from the Gross-Llewellyn Smith sum rule", Phys. Rev. Lett. **81**: 3595, (1998)

Synergistic Activities

1. Co-spokesperson, MINERvA Collaboration, 2010-present
2. Group Leader, MINERvA Department in Neutrino Division at Fermilab, 2013-present
3. Project Manager, MINERvA Project, 2005-2010
4. Level 2 Manager for Secondary Beamline Monitoring, NuMI Project, 2000-2004
5. Chair of Particle Data Group Advisory Committee, 2014

Collaborators and Other Affiliations

Members of the MINERvA Collaboration at Fermilab (70 physicists)
Members of the MINOS Collaboration at Fermilab (200 physicists)
Members of the NuTeV Collaboration at Fermilab (35 physicists)
Members of the E799/E773 Collaborations at Fermilab (40 physicists)

Graduate Advisor: Prof. Yau Wah, University of Chicago

Current Postdoctoral Advisees (3): Dr. Minerba Betancourt, Dr. Jyotsna Osta, Dr. Manungu Kiveni

Biographical Sketch of Christopher Michael Mauger

Education and Training

Rutgers University	Physics	B.S. 1994
SUNY Stony Brook	Physics	Ph.D. 2002

Postdoctoral Scholar, California Institute of Technology, 2002-2006
Senior Postdoctoral Scholar, California Institute of Technology, 2006-2008

Research and Professional Experience

Associate Professor of Physics, University of Pennsylvania, from January, 2016
Scientist 3, Physics Division, Los Alamos National Laboratory, 2011 – 2016
Scientist 2, Physics Division, Los Alamos National Laboratory, 2008 – 2011
PI, LANL LDRD Exploratory Research Project, 2014 – present
Spokesperson, CAPTAIN Collaboration, 2014 – present
PI, LANL LDRD Directed Research Project, 2011-2014
Project Manager, LBNE Near Detector Systems, 2009-2015
DOE Laboratory Early Career Awardee, 2010-2015

Publications

1. “Scientific Opportunities with the Long-Baseline Neutrino Experiment", C. Adams et al. [LBNE Collaboration].
2. “The CAPTAIN Detector and Physics Program", H. Berns et al. [The CAPTAIN Collaboration]. arXiv:1309.1740 [physics.ins-det]
3. “Liquid Argon Time Projection Chamber Research and Development in the United States", B. Baller, N. Buchanan, F. Cavanna, H. Chen, E. Church, V. Gehman, H. Greenlee and E. Guardincerri et al.. JINST 9, T05005 (2014)
4. “The Long-Baseline Neutrino Experiment: Exploring Fundamental Symmetries of the Universe", C. Adams et al. [LBNE Collaboration].arXiv:1307.7335
5. “The 2010 Interim Report of the Long-Baseline Neutrino Experiment Collaboration Physics Working Groups" T. Akiri et al. [LBNE Collaboration]. arXiv:1110.6249
6. “Precision Measurement of Neutrino Oscillation Parameters with KamLAND", S. Abe et al. [KamLAND Collaboration]. Phys. Rev. Lett. 100, 221803 (2008)
7. “Experimental investigation of geologically produced antineutrinos with KamLAND", T. Araki, S. Enomoto, K. Furuno, Y. Gando, K. Ichimura, H. Ikeda, K. Inoue and Y. Kishimoto et al., Nature 436, 499 (2005).
8. “Evidence for muon neutrino oscillation in an accelerator-based experiment", E. Aliu et al. [K2K Collaboration]. Phys. Rev. Lett. 94, 081802 (2005)
9. “Measurement of single pi0 production in neutral current neutrino interactions with water by a 1.3-GeV wide band muon neutrino beam", S. Nakayama, C. Mauger, et al. [K2K Collaboration]. Phys. Lett. B 619, 255 (2005)
10. “Measurement of neutrino oscillation with KamLAND: Evidence of spectral distortion", T. Araki et al. [KamLAND Collaboration]. Phys. Rev. Lett. 94, 081801 (2005)

Synergistic Activities

1. PI, LANL LDRD Research Projects, 2011-2014, 2014 – present
2. Spokesperson, CAPTAIN Collaboration, 2014 – present
3. Project Manager, LBNE Near Detector Systems, 2009-2015
4. Organizer of Neutrino-Nucleus Interactions for Current and Next Generation Neutrino Oscillation Experiments" workshop at the Institute for Nuclear Theory at the University of Washington (December 2013)
5. LBNE Executive Committee Member, 2010-2012

Collaborators and Other Affiliations

Members of CAPTAIN Collaboration
Members of DUNE Collaboration
Members of LBNE Collaboration
Members of WATCHMAN Collaboration
Members of NuSTEC Collaboration
Members of NEDM Collaboration
Members of Daya Bay Collaboration
Members of KamLAND Collaboration
Members of K2K Collaboration
Members of Super-Kamiokande Collaboration

Graduate Advisor: Professor Chang Kee Jung (Stony Brook)

Postdoctoral Advisees

Dr. Elena Guardincerri (2011-2014), Currently Staff Member at LANL
Dr. Qiuguang Liu (2013-present)
Dr. Charles Taylor (2013-present)

Biographical Sketch of Keith Robert Rielage

Education and Training

Miami University, Oxford, OH: Physics, B.S.; Political Science, B.A. 1996
Washington University, St. Louis, MO: Physics M.S. 1998
Washington University, St. Louis, MO: Physics Ph.D. 2002, Thesis: The Use of Scintillating Fibers in High-Energy Astrophysics
University of Washington, Seattle, WA: Postdoctoral Research Associate, 2003-5
Los Alamos National Laboratory: Postdoctoral Research Fellow, 2005-2008

Professional Experience

Team Leader, P-23 Weak Interactions/Astrophysics Team, Los Alamos National Laboratory, 2015-present
Staff Member, Physics Division, Los Alamos National Laboratory, 2008-present
Adjunct Associate Professor, Department of Physics and Astronomy, University of New Mexico, 2008-present
Visiting Assistant Professor, Department of Physics, Kenyon College, 2002-3

Selected Publications

Akashi-Ronquest, M., et al. (2014) Improving photoelectron counting and particle identification in scintillation detectors with Bayesian techniques. arXiv:1408.1914.

Bodmer, B., Phan, N., Gold, M., Loomba, D., Matthews, J.A.J. and Rielage, K. (2014) Measurement of optical attenuation in acrylic light guides for a dark matter detector. JINST 9, P02002.

The SNO Collaboration. (2014) A search for astrophysical burst signals at the Sudbury Neutrino Observatory. Astro. Part., 55, 1.

The Majorana Collaboration, (2014) The MAJORANA Demonstrator Neutrinoless Double-Beta Decay Experiment, Adv. High Energy Phys. 2014, 365432.

Rielage, K. (2013) Photon detection in the Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos (CAPTAIN). JINST, 8, C09002.

The SNO Collaboration. (2013) Combined analysis of all three phases of solar neutrino data from the Sudbury Neutrino Observatory. Phys. Rev. C, 88, 025501.

The Majorana Collaboration. (2013) Characteristics of signals originating near the Lithium diffused N+ contact of high purity germanium P-type point contact detectors. NIM, A, 701, 176.

The SNO Collaboration. (2013) Measurement of the _e and total 8B solar neutrino fluxes with the Sudbury Neutrino Observatory phase-III data set. Phys. Rev. C, 87, 015502.

Gehman, V.M., et al. (2011) Fluorescence efficiency and visible reemission spectrum of tetraphenyl butadiene films at extreme ultraviolet wavelengths. NIM, A, 654, 116.

The SNO Collaboration. (2008) Independent Measurement of the Total Active 8B Solar Neutrino Flux Using an Array of 3He Proportional Counters at the Sudbury Neutrino Observatory. PRL, 101, 111301.

Synergistic Activities

1) Member, LANSCE Neutron Science Program Advisory Committee, 2015
2) Chair, LANL LDRD Nuclear and Particle Physics, Astrophysics and Cosmology Exploratory Research Category Team, 2013 and 2014, Member, 2012
3) Member, Scientific Advisory Committee, SNOLAB Grand Opening Workshop, 2012
4) Member, Local Organizing Committee, 2nd Annual Workshop on Advances in Neutrino Technology, 2010
5) Young Scientist Representative, Sudbury Neutrino Observatory Scientific Board, 2004-5

Collaborators and Other Affiliations

MAJORANA Collaboration
CAPTAIN Collaboration
MiniCLEAN Collaboration
WATCHMAN Collaboration
Sudbury Neutrino Observatory Collaboration

Graduate Advisor: Prof. M.H. Israel (Washington University in St. Louis)
Postdoctoral Advisors: Prof. R.G.H Robertson, Prof. J.F. Wilkerson (University of Washington), and Dr. A. Hime (LANL)

Graduate and Postdoctoral Advisees during the last 10 years:

Former Postdoctoral Advisees (6): Dr. Stan Seibert (Mobi), Dr. Raul Hennings-Yeomans (UC-Berkeley), Dr. Mitzi Boswell (LANL), Dr. Mary Kidd (Tennessee Tech), Dr. Michael Ronquest (CCRi), Dr. John Goett (LANL)
Current Postdoctoral Advisees (3): Dr. Wenqin Xu, Dr. Ralph Massarczyk, Dr. Pinghan Chu
Former Graduate Students (1): Dr. Stephen Jaditz (MIT)

References

[1] DUNE Conceptual Design Report. https://web.fnal.gov/project/LBNF/ReviewsAndAssessments/LBNF_DUNE%20DOE%20CD-1%20Refresh%20Review/SitePages/Conceptual%20Design%20Report.aspx.

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[8] L. Camilleri. MicroBooNE. *Nucl. Phys. Proc. Suppl.*, 237-238:181–183, 2013.

[9] B. Rebel, M. Adamowski, W. Jaskierny, H. Jostlein, C. Kendziora, R. Plunkett, S. Pordes, R. Schmitt, T. Tope, and T. Yang. Results from the Fermilab materials test stand and status of the liquid argon purity demonstrator. *J. Phys. Conf. Ser.*, 308:012023, 2011.

[10] C. Anderson et al. First Measurements of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon. *Phys. Rev. Lett.*, 108:161802, 2012.

[11] C. Andreopoulos et al. The GENIE Neutrino Monte Carlo Generator. *Nucl. Instrum. Meth.*, A614:87–104, 2010.

[12] S. Agostinelli et al. GEANT4: A Simulation toolkit. *Nucl. Instrum. Meth.*, A506:250–303, 2003.

[13] John Allison et al. Geant4 developments and applications. *IEEE Trans. Nucl. Sci.*, 53:270, 2006.

[14] R. Brun and F. Rademakers. ROOT: An object oriented data analysis framework. *Nucl. Instrum. Meth.*, A389:81–86, 1997.

[15] G. Barrand et al. GAUDI - A software architecture and framework for building HEP data processing applications. *Comput. Phys. Commun.*, 140:45–55, 2001.

[16] G. N. Perdue et al. The MINERνA Data Acquisition System and Infrastructure. *Nucl. Instrum. Meth.*, A694:179–192, 2012.

[17] `https://coda.jlab.org/drupal/`.

Appendix 4: University of Rochester Facilities & Other Resources

The University of Rochester is a private research and teaching university. The Department of Physics and Astronomy has a long and distinguished history of research in both experimental and theoretical particle physics, and has extensive involvement in leading experimental collaborations. In particular, the group has an established relationship with Fermi National Accelerator Laboratory and has recent experience in building large-scale detectors on the FNAL site with partnerships between Rochester personnel and Fermilab staff. Examples of these partnerships include the CDF plug calorimeter, the CMS hadronic calorimeter and the MINERvA detector. Such collaborative arrangements located at the national lab allow us to bring ideas developed and prototyped in a University environment to full-scale fruition through collaborative use of space, engineering, and computing resources hosted at Fermilab

University of Rochester Department of Physics and Astronomy Specialized Service Center:

The Department's Sidney W. Barnes Research Laboratory (SWBRL) offers a machining space, and mechanical engineering and electronics support, to assist researchers with experiments, detector development, and accelerator projects. For short-term projects, the SWBRL is able to employ engineers, drafters and technicians to augment the capabilities of the shop staff. The University's College also maintains a large and versatile machine shop that complements the skills of the SWBRL. There are additional extensive resources (specialized machining and electronics service centers) at the University's DOE funded Laboratory for Laser Energetics.

Also within the Sidney W. Barnes Research Laboratory (SWBRL), the High Energy Physics group shares computing resources with other research groups in the department, including two full-time system managers employed by the Department. These services involve setting up machines so that they can be used for scientific computing, experimental control, and data acquisition.

Sub-Awardee Institution: University of Pennsylvania

The High Energy Physics Group in the Physics and Astronomy Department at the University of Pennsylvania has access to ample laboratory space and a fully-equipped machine shop. The Penn Instrumentation Group is also a significant resource for electronics and other instrumentation development. Professor Mauger has been afforded significant laboratory space that will be outfitted for cryogenic effort.

Collaborating Institutions: Fermi National Acceleratory Laboratory and Los Alamos National Laboratory

Facilities available to this project from Fermi National Accelerator laboratory are described in the letter of endorsement from FNAL that is appended to this appendix. Facilities available to the project from Los Alamos National Laboratory are described in the LANL letter of endorsement in Appendix 5.

Fermilab

August 24, 2015

To: University of Rochester Research Office

Re: Endorsement of Proposal "CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab"

Fermi National Accelerator Laboratory (Fermilab) is pleased to endorse the proposal from the University of Rochester in response to announcement DE-FOA-0001381 titled "CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab".

The CAPTAIN MINERvA proposal that was submitted to Fermilab's Physics Advisory Committee in June 2015 received Stage I approval, which means that detailed planning for the detector's installation will begin.

Fermilab design efforts will include planning for a space above ground with appropriate crane coverage, utilities, and ventilation where the CAPTAIN detector can be assembled and tested, and will also investigate how to prepare the MINOS Near Detector Hall underground so that the CAPTAIN detector can be installed on the NuMI beamline, upstream of the MINERvA detector.

Fermilab, as host laboratory, will organize and assign personnel to actively participate in technical, management and safety reviews of the designs described in the CAPTAIN MINERvA proposal. The technical and management reviews will take place through the Project Management Group process that is already in place at Fermilab, and the Safety reviews will proceed through established procedures in the appropriate divisions and sections.

Operation of the NuMI beam during the CAPTAIN MINERvA run is currently part of Fermilab's long range schedule. Once adequate resources to carry out the design, construction and installation of the detector have been identified, Fermilab will plan to provide adequate technical, computing and scientific effort to operate the experiment successfully, subject to the usual physics and budgetary review processes already in place.

Best regards,

Greg Bock

Greg Bock
Deputy Chief Research Officer

Fermi National Accelerator Laboratory / Kirk and Pine Street / P.O. Box 500 / Batavia, IL 60510 / 630.840.3000 / www.fnal.gov / fermilab@fnal.gov
Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Appendix 5: Equipment

The equipment available to the particle physics group at the University of Rochester includes the specialized facilities specified in appendix 5. Common testing and diagnostic equipment is available in the various shops for the specialized applications of the various research projects. The mechanical shop has computer controlled milling machines and lathes for metal work which are available to the group. Equipment available at the sub-awardee institution, University of Pennsylvania is also summarized in appendix 4.

Specific equipment outside of the scope of this project to be supplied by the Los Alamos National Laboratory is described in the appended letter of endorsement from LANL.

Los Alamos
NATIONAL LABORATORY
EST. 1943

P-23 Neutron Science & Technology,
Physics Division
PO Box 1663, MS H803
Los Alamos, New Mexico 87545
505-664-0090/Fax 505-665-4121

Date: August 24, 2015

To: University of Rochester Research Office

Endorsement of Proposal "CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab"

Los Alamos National Laboratory (LANL) is pleased to endorse the proposal from the University of Rochester in response to announcement DE-FOA-0001381 titled "CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab". LANL is prepared to fulfill the work outlined in the Statement of Work after execution of the subcontract should this proposal be awarded. In addition, LANL will supply the equipment on the attached list.

Best regards,

Eric Brown, Ph.D.
P-23 Group Leader

8/24/15

Rajan Gupta, Ph.D.
LANL HEP Program Manager

8/24/2015

LANL Provided Equipment:

1) CAPTAIN cryostat – ASME Section VIII Division 1 pressure vessel built by Eden Cryogenics for confinement of liquid argon for the experiment
2) Cryogenic skid – built by Eden Cryogenics to purify the liquid argon with inline filtration and recirculation pump
3) Electronics – 2000 channels of electronics developed by MicroBooNE to read out a time projection chamber including cold frontends, digitizers, and cold and warm cabling
4) High voltage feedthrough for TPC (from UCLA)
5) TPC frame parts to construct a field cage but without termination boards or wires
6) Laser calibration system including laser, optics and periscope
7) Photomultiplier tubes (16) – Hamamatsu R8520 PMTs with bases for use as the photon detection system
8) H2O and O2 monitoring system
9) Condenser system – may be useful but depends on final design of recirculation system
10) High Voltage supply for TPC
11) Vacuum pumps for gas/cryogenics system

CAPTAIN-MINERvA Data Management Plan

Data Types and Sources
The raw data for CAPTAIN-MINERvA consists of "digits" for each of the CAPTAIN, MINERvA, and MINOS ND detector elements, and represent either drift wire signals or photo-multiplier tube outputs. These elements are digitized and stored by the data acquisition in a binary format. Digits consist of digitized voltages, timing and detector element metadata. The raw binary file is not readable except by custom internal code and requires separate channel mapping tables and calibration constants to reconstruct into data corresponding to the physical event, i.e. particle momenta and energies. Reconstructed events are saved in what are traditionally called data-summary files (DST, where T used to refer to tape). As is common in particle physics experiments, all raw data is not necessarily saved in order to save on storage space. (The raw data set for CAPTAIN in the CAPTAIN-MINERvA experiment is expected to be as much as 25 TB per week of running.) The data does not contain any personal identifiable, or other confidential information, and therefore does not require special security measures to protect confidentiality.

Content and Format
The format of the reconstructed data is that of CERN's ROOT but requires custom code to fully access and interpret. The required code is publicly available. The full reconstructed data set and code will be preserved for a period of time following the completion of the experiment, the period of time to be decided by the CAPTAIN-MINERvA collaboration in consultation with DOE and the larger scientific community.

Sharing and Preservation
The CAPTAIN-MINERvA collaboration views the collected data as a public asset and intends to make it available to the extent that this is practical. Access to the data will require access to the data archive and, due to its complex nature, some level of collaboration with CAPTAIN-MINERvA. Any re-analysis of the data will therefore require cooperation with the CAPTAIN-MINERvA collaboration, and any publicly presented work must acknowledge the collaboration and appropriate funding agencies. Published CAPTAIN-MINERvA plots, tables, parameters, and associated metadata, such as figure captions, will be made available in machine-readable electronic form through publicly accessible platforms in accordance with HEP formatting standards for the dissemination of such.

Protection
The CAPTAIN-MINERvA data are expected to be archived on Fermi National Accelerator (FNAL) computers that are operated by FNAL for the scientific research community. In the future, data sets may be archived at other DOE sites such as NERSC.

Rationale
The proposed plan is consistent with current practices used with large and complex data typical of large particle physics experiments. It is consistent with both the CAPTAIN and MINERvA data management plans. It has been reviewed by scientific computing personnel at FNAL and comments from that review have been incorporated into this plan.

University of Rochester: Budget for DOE FOA-0001381

CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab

Budget Period: 3/1/16-2/28/21	DOE Funded Person-mos. per budget year									
	CAL	ACAD	SUMR	Budget Year 1	Budget Year 2	Budget Year 3	Budget Year 4	Budget Year 5	Funds Requested ($) All Years	
A. Senior/Key Personnel			**Total Senior Personnel (1-8)**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	
1. Kevin McFarland				$ -	$ -	$ -	$ -	$ -	$ -	
									$ -	
									$ -	
B. Other Personnel (Number in Brackets)			**Total Other Personnel**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	
									$ -	
									$ -	
									$ -	
Total Personnel Costs			**Total Salaries and Wages (A+B)**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	
C. Permanent Equipment			**Total Permanent Equipment**	$ 684,798	$ 179,468	$ 23,748			**$ 888,014**	*
D. Travel			**Total Travel**	**$ 12,460**	**$ 11,138**	**$ -**	**$ -**	**$ -**	**$ 23,598**	
1. Domestic Travel Costs				$ 12,460	$ 11,138				$ 23,598	
2. Foreign Travel Costs									$ -	
E. Trainee/Participant Costs (Total Partic: 0)			**Total**	$ -	$ -	$ -	$ -	$ -	**$ -**	*
1. Tuition/Fees/Health Insurance									$ -	
2. Stipends									$ -	
3. Travel									$ -	
4. Subsistence									$ -	
5. Other									$ -	
F. Other Direct Costs			**Total Other Direct Costs**	**$ 1,426,824**	**$ 259,864**	**$ 24,079**	**$ -**	**$ -**	**$ 1,710,767**	
1. Materials and Supplies				$ -	$ 39,312				**$ 39,312**	
2. Publication Costs/Documentation/Dissemination									**$ -**	
3. Consultant Services									**$ -**	
4. Computer (ADP) Services									**$ -**	
5. Subawards/Consortium/Contractual Costs				$ 575,480	$ 2,880				**$ 578,360**	**
6. Equipment or Facility Rental/User Fees									**$ -**	
7. Alterations and Renovations									**$ -**	
8. Specialized Services Facility				$ 840,879	$ 207,877	$ 24,079			**$ 1,072,835**	*
9. FNAL Purchase Order (for Travel)				$ 10,465	$ 9,795				**$ 20,260**	
10. Other									**$ -**	
G. Direct Costs			**Total Direct Costs (A through F)**	$ 2,124,082	$ 450,470	$ 47,827	$ -	$ -	**$ 2,622,379**	
H. Indirect Costs			**Total Indirect Costs**	$ 12,940	$ 16,266	$ -	$ -	$ -	**$ 29,206**	
	Indirect Cost Rate		**Indirect Cost Base**							
MDTC off campus	27.00%		$ 108,170	$ 12,940	$ 16,266	$ -	$ -	$ -	**$ 29,206**	
									$ -	
I. Direct and Indirect Costs			**Total and Indirect Costs (G + H)**	**$ 2,137,022**	**$ 466,736**	**$ 47,827**	**$ -**	**$ -**	**$ 2,651,585**	
J. Fee			**Total Fee**						**$ -**	
K. Cost of Project			**Total Cost of Project (I+J)**						**$ 2,651,585**	

* exempt from indirect

** indirect incurred on first $25,000 of each subcontract

NOTE: NOT INCLUDED IN DOE PROPOSAL SUBMISSION, USED FOR INTERNAL PURPOSES ONLY

RESEARCH & RELATED BUDGET - Budget Period 1

OMB Number: 4040-0001
Expiration Date: 6/30/2016

ORGANIZATIONAL DUNS: 0412941090000 **Enter name of Organization:** University of Rochester

Budget Type: ☒ Project ☐ Subaward/Consortium **Budget Period:** 1 **Start Date:** 03/01/2016 **End Date:** 02/28/2017

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Kevin		McFarland						0.00	0.00	0.00

Project Role: PD/PI

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 0.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						

Total Number Other Personnel

Total Other Personnel

Total Salary, Wages and Fringe Benefits (A+B) 0.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment item	Funds Requested ($)
Cryostat, Cryogenic and Detector Subsystems	315,384.00
Integrated Cryogenic System for the CAPTAIN-MINERvA Cryostat	369,414.00

Additional Equipment: Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file	
Total Equipment	684,798.00

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	12,460.00
2. Foreign Travel Costs	
Total Travel Cost	12,460.00

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

		Funds Requested ($)
1.	Materials and Supplies	
2.	Publication Costs	
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	575,480.00
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	Specialized Services Facility	840,879.00
9.	FNAL Purchase Order for Travel	10,465.00
10.		
	Total Other Direct Costs	1,426,824.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	2,124,082.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MDTC Off Campus	27.00	47,926.00	12,940.00
		Total Indirect Costs	12,940.00

Cognizant Federal Agency (Agency Name, POC Name, and POC Phone Number): DHHS, Michael Leonard, 212-264-2069

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	2,137,022.00

J. Fee

Funds Requested ($)

K. Budget Justification

(Only attach one file.) BudgetJustif CAPTAIN MINERvA.pdf

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Budget Period 2

OMB Number: 4040-0001
Expiration Date: 6/30/2016

ORGANIZATIONAL DUNS: 0412941090000 **Enter name of Organization:** University of Rochester

Budget Type: ☒ Project ☐ Subaward/Consortium **Budget Period: 2** **Start Date:** 03/01/2017 **End Date:** 02/28/2018

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Kevin		McFarland						0.00	0.00	0.00

Project Role: PD/PI

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 0.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						

Total Number Other Personnel

Total Other Personnel

Total Salary, Wages and Fringe Benefits (A+B) 0.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment item	Funds Requested ($)
Cryostat, Cryogenic and Detector Subsystems	151,804.00
Integrated Cryogenic System for the CAPTAIN-MINERvA Cryostat	27,664.00

Additional Equipment: Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file

Total Equipment 179,468.00

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	11,138.00
2. Foreign Travel Costs	
Total Travel Cost	11,138.00

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

		Funds Requested ($)
1.	Materials and Supplies	39,312.00
2.	Publication Costs	
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	2,880.00
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	Specialized Services Facility	207,877.00
9.	FNAL Purchase Order for Travel	9,795.00
10.		
	Total Other Direct Costs	259,864.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	450,470.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MDTC Off Campus	27.00	60,244.00	16,266.00
	Total Indirect Costs		16,266.00

Cognizant Federal Agency (Agency Name, POC Name, and POC Phone Number): DHHS, Michael Leonard, 212-264-2069

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	466,736.00

J. Fee

Funds Requested ($)

K. Budget Justification

(Only attach one file.) BudgetJustif CAPTAIN MINERvA.pdf

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Budget Period 3

OMB Number: 4040-0001
Expiration Date: 6/30/2016

ORGANIZATIONAL DUNS: 0412941090000 **Enter name of Organization:** University of Rochester

Budget Type: ☒ Project ☐ Subaward/Consortium **Budget Period: 3** **Start Date:** 03/01/2018 **End Date:** 02/28/2019

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Kevin		McFarland						0.00	0.00	0.00

Project Role: PD/PI

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 0.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						

Total Number Other Personnel

Total Other Personnel

Total Salary, Wages and Fringe Benefits (A+B) 0.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment Item	Funds Requested ($)
Cryostat, Cryogenic and Detector Subsystems	23,748.00

Additional Equipment: Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file	
Total Equipment	23,748.00

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2. Foreign Travel Costs	
Total Travel Cost	

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

		Funds Requested ($)
1.	Materials and Supplies	
2.	Publication Costs	
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	Specialized Services Facility	24,079.00
9.	FNAL Purchase Order for Travel	0.00
10.		
	Total Other Direct Costs	24,079.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	47,827.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MDTC Off Campus	27.00	0.00	0.00
		Total Indirect Costs	0.00

Cognizant Federal Agency (Agency Name, POC Name, and POC Phone Number): DHHS, Michael Leonard, 212-264-2069

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	47,827.00

J. Fee

Funds Requested ($)

K. Budget Justification

(Only attach one file.) BudgetJustif CAPTAIN MINERvA.pdf

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Budget Period 4

OMB Number: 4040-0001
Expiration Date: 6/30/2016

ORGANIZATIONAL DUNS: 0412941090000 **Enter name of Organization:** University of Rochester

Budget Type: ☒ Project ☐ Subaward/Consortium **Budget Period:** 4 **Start Date:** 03/01/2019 **End Date:** 02/29/2020

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Kevin		McFarland						0.00	0.00	0.00

Project Role: PD/PI

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 0.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						

Total Number Other Personnel

Total Other Personnel

Total Salary, Wages and Fringe Benefits (A+B) 0.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment item	Funds Requested ($)
0	0.00

Additional Equipment: Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file

Total Equipment 0.00

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	0.00
2. Foreign Travel Costs	
Total Travel Cost	0.00

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

		Funds Requested ($)
1.	Materials and Supplies	
2.	Publication Costs	
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	0.00
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	Specialized Services Facility	0.00
9.	FNAL Purchase Order for Travel	0.00
10.		
	Total Other Direct Costs	0.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	0.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MDTC Off Campus	27.00	0.00	0.00

Total Indirect Costs 0.00

Cognizant Federal Agency (Agency Name, POC Name, and POC Phone Number): DHHS, Michael Leonard, 212-264-2069

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	0.00

J. Fee

Funds Requested ($):

K. Budget Justification

(Only attach one file.) BudgetJustif CAPTAIN MINERvA.pdf

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Budget Period 5

OMB Number: 4040-0001
Expiration Date: 6/30/2016

ORGANIZATIONAL DUNS: 0412941090000 **Enter name of Organization:** University of Rochester

Budget Type: ☒ Project ☐ Subaward/Consortium **Budget Period:** 5 **Start Date:** 03/01/2020 **End Date:** 02/28/2021

A. Senior/Key Person

Prefix	First	Middle	Last	Suffix	Base Salary ($)	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Kevin		McFarland						0.00	0.00	0.00

Project Role: PD/PI

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

Total Funds requested for all Senior Key Persons in the attached file

Total Senior/Key Person 0.00

B. Other Personnel

Number of Personnel	Project Role	Months Cal.	Months Acad.	Months Sum.	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						

Total Number Other Personnel

Total Other Personnel

Total Salary, Wages and Fringe Benefits (A+B) 0.00

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

Equipment Item	Funds Requested ($)

Additional Equipment: Add Attachment | Delete Attachment | View Attachment

Total funds requested for all equipment listed in the attached file

Total Equipment

D. Travel

	Funds Requested ($)
1. Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2. Foreign Travel Costs	
Total Travel Cost	

E. Participant/Trainee Support Costs

	Funds Requested ($)
1. Tuition/Fees/Health Insurance	
2. Stipends	
3. Travel	
4. Subsistence	
5. Other	
Number of Participants/Trainees — **Total Participant/Trainee Support Costs**	

F. Other Direct Costs

		Funds Requested ($)
1.	Materials and Supplies	
2.	Publication Costs	
3.	Consultant Services	
4.	ADP/Computer Services	
5.	Subawards/Consortium/Contractual Costs	
6.	Equipment or Facility Rental/User Fees	
7.	Alterations and Renovations	
8.	Specialized Services Facility	0.00
9.	FNAL Purchase Order for Travel	0.00
10.		
	Total Other Direct Costs	0.00

G. Direct Costs

	Funds Requested ($)
Total Direct Costs (A thru F)	0.00

H. Indirect Costs

Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MDTC Off Campus	27.00	0.00	0.00

Total Indirect Costs	0.00

Cognizant Federal Agency (Agency Name, POC Name, and POC Phone Number): DHHS, Michael Leonard, 212-264-2069

I. Total Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	0.00

J. Fee

Funds Requested ($)

K. Budget Justification

(Only attach one file.) BudgetJustif CAPTAIN MINERvA.pdf

Add Attachment | Delete Attachment | View Attachment

RESEARCH & RELATED BUDGET - Cumulative Budget

	Totals ($)	
Section A, Senior/Key Person		0.00
Section B, Other Personnel		
Total Number Other Personnel		
Total Salary, Wages and Fringe Benefits (A+B)		0.00
Section C, Equipment		888,014.00
Section D, Travel		23,598.00
1. Domestic	23,598.00	
2. Foreign		
Section E, Participant/Trainee Support Costs		
1. Tuition/Fees/Health Insurance		
2. Stipends		
3. Travel		
4. Subsistence		
5. Other		
6. Number of Participants/Trainees		
Section F, Other Direct Costs		1,710,767.00
1. Materials and Supplies	39,312.00	
2. Publication Costs		
3. Consultant Services		
4. ADP/Computer Services		
5. Subawards/Consortium/Contractual Costs	578,360.00	
6. Equipment or Facility Rental/User Fees		
7. Alterations and Renovations		
8. Other 1	1,072,835.00	
9. Other 2	20,260.00	
10. Other 3		
Section G, Direct Costs (A thru F)		2,622,379.00
Section H, Indirect Costs		29,206.00
Section I, Total Direct and Indirect Costs (G + H)		2,651,585.00
Section J, Fee		

UNIVERSITY OF ROCHESTER
CUMULATIVE BUDGET JUSTIFICATION FY16-FY20

CAPTAIN MINERvA: Construction, Commissioning and Installation of the CAPTAIN Detector in the NuMI Beamline at Fermilab

Costs that appear in this budget are estimated using a schedule for work developed in consultation with engineers at Fermilab and Los Alamos National Lab. The schedule is technically limited, and does not take into account availability of unique facilities at Fermilab in the installation process, such as access to the NuMI near hall shaft for vent piping installation. All costs, except travel, have a 40% contingency added. Escalation in outyears assumes 4% inflation. More details about the schedule of work that drives the budget and its profile is appended to the end of this justification.

The CAPTAIN MINERvA program includes operation and physics analysis in years 3-5 of this proposal. No support is request for the scientists involved in this, nor is support requested for operations of the detector, as per the guidance in the supplementary information provided with the FOA. Therefore, there is no funding request in years 4 and 5.

A. SENIOR PERSONNEL $ 0

PI effort on this project for Kevin McFarland will be funded by the University of Rochester DOE base grant (DE-SC0008475) that supports the core effort for this initiative for intensity frontier activities. The PI will supervise the work of the postdocs and graduate students on this project.

B. OTHER PERSONNEL $ 0

University of Rochester postdoc and graduate student effort on this project will be funded by the University of Rochester DOE base grant (DE-SC0008475) that supports the core effort for this initiative for intensity frontier activities.

A+B. TOTAL SALARY, WAGES AND FRINGE BENEFITS $ 0

C. EQUIPMENT $ 888,014

The primary deliverable of this proposal is the CAPTAIN MINERvA cryostat and time projection chamber, delivered in a state that is ready to fill with liquid argon and operate. Several vendors and national laboratories will provide discrete elements that contribute to this integrated component.

Cryostat, Cryogenic and Detector Subsystems

Los Alamos National Laboratory (LANL) will produce the cryostat, cryogenic and detector subsystems and deliver them to the project site at Fermi National Accelerator Laboratory (FNAL). LANL was the lead institution in developing the "Mini-CAPTAIN" detector which is the prototype for CAPTAIN-MINERvA, and as such LANL possesses unique experience, personnel and capabilities to build this specialized piece of equipment. Note that key portions of the CAPTAIN MINERvA detector, notably the cryostat and significant portions of the cryogenic system, are already under construction at Los Alamos and these already funded components are outside the scope of this proposal. Dr. Keith Rielage will oversee the construction of the cryostat, portions of the cryogenic system, time projection chamber and

associated electronics, the purification system, and the laser calibration system. Los Alamos National Laboratory (LANL) will also support the delivery of these items to FNAL, consulting effort to work on the assembly and integration of these provided parts into the full CAPTAIN MINERvA detector.

Integrated Cryogenic System for the CAPTAIN-MINERvA Cryostat
Fermilab National Accelerator Laboratory (FNAL) will deliver an integrated cryogenic system for the CAPTAIN-MINERvA cryostat that will be capable of passing safety reviews and being operated in both surface and underground locations at FNAL. They will also deliver the hardware necessary to safely support and contain the CAPTAIN-MINERvA detector, electronics and controls systems. FNAL is the host laboratory for the ultimate location of the CAPTAIN-MINERvA experiment, and as such has unique expertise and responsibility for safety and controls systems, as well as systems which must closely integrate with the physical locations of CAPTAIN MINERvA. Dr. Deborah Harris of the FNAL Neutrino Division will oversee the production of this system, and will be carried out by technical staff from the FNAL Neutrino and Particle Physics departments.

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cryostat, Cryogenic and Detector Subsystems	$315,384	$151,804	$ 23,748			$490,936
Integrated Cryogenic System for the CAPTAIN-MINERvA Cryostat	$369,414	$ 27,664				$397,078
Total	$684,798	$179,468	$ 23,748			$888,014

D. TRAVEL $ 23,598

We request $12,460 for travel in the first year and 11,138 in year two. Travel costs include airfare, lodging, food and incidentals to Fermilab.

In addition to this, in *Section F. 10. Other* below, we have budgeted $10,465 for travel in the first year and 9,795 in year two charged to a FNAL purchase order. We will detail all the travel that is budgeted in this section of the justification.

Year 1 Travel to Fermilab	Initial Review 3 day trip	Intermediate Review 3 day trip	Assembly Trip 5 day trip	Assembly Trip 5 day trip	Total
McFarland (Rochester)	$1,286	$1,286			
Whitehead (U of Houston)	$1,286	$1,286			
McGrew (Stony Brook)	$1,286	$1,286			
Technologist (LANL)	$1,635	$1,635	$2,167	$2,167	
Engineer (LANL)	$1,635	$1,636	$2,167	$2,167	
					$22,925

Year 2 Travel to Fermilab	Final Review 3 day trip	Assembly Trip 5 day trip	Assembly Trip 5 day trip	Commissioning Trip 5 day trip	Total
McFarland (Rochester)	$1,337				
Whitehead (U of Houston)	$1,337				
McGrew (Stony Brook)	$1,337				
Technologist (LANL)	$1,702			$2,253	
Engineer (LANL)	$1,702	$2,253		$2,253	
Technician (LANL)		$2,253	$2,253	$2,253	
					$20,933

E. PARTICIPANT/TRAINEE COSTS $ 0

F. OTHER DIRECT COSTS $1,710,767

1. Materials and Supplies: $ 39,312

The materials and supplies budget supports the purchase of three fills of liquid argon in year 2.

5. Subwards/Consortium/Contractual Costs $ 578,360

Subaward for University of Pennsylvania
The two components to the subaward budget are equipment and travel. Please see the attached budget and justification from University of Pennsylvania (Penn) for details.

Equipment includes the following: TPC Hardware, Cryocoolers, Indium Seals, Clean Tent, Cryostat Hardware, Cabling, Controls Hardware, Cryogenic and Gas Piping Manifolds

Travel: The travel budget supports trips from Penn to Fermilab by the Penn senior investigator, Mauger, for the reviews of the project.

8. Other: Specialized Services Facility $ 1,072,835

A budget for the use of the S.W. Barnes Research Laboratory (SWBRL) is requested. SWBRL is a fully-costed shop in the Department of Physics and Astronomy that provides mechanical design, computing, technical and other research support services. In accordance with the University of Rochester negotiated F&A rate, indirect costs are excluded from charges of fully-costed shops. Costs are charged based on University approved hourly rates in accordance with 2 CFR 200.

Specialized Service Facility: Engineering, Drafting and Technician Services
We will utilize SWBRL engineer and drafting services to provide design and drafting packages required for item specification and equipment purchases through the University of Pennsylvania subcontract, as

well as documentation required for FNAL safety reviews. During the first year, the proposed activities are primarily the design and drafting of the cryogenic and controls systems appropriate for underground operations.

The engineer(s) will complete many key tasks including design and commissioning of CAPTAIN. *Engineering Design* tasks will include: finalize the master piping and instrumentation diagram (P&ID), design the vent stack, perform ODH calculations for a review by Fermilab, specify heat exchangers for the 600 watt refrigerators, design the manifold box for refrigerators, size piping, design the piping layout in the NuMI cavern and any alterations necessary for the surface tests before installation, write an engineering note documenting the design and safety calculations for the CAPTAIN support frame and the TPC installation frame and thermal baffles, document the instruments and valves and related safety calculations, write notes describing the piping, specify the number, capacity and placement of necessary relief valves for underground operation. The engineer will design cable routing and needed fixtures and the gas panels. Finally, the engineer will design the TPC wire stringing workflow. This work will be done in close consultation with Fermilab neutrino division cryogenic engineers. The efficacy of this working relationship has been reviewed by Barry Norris, group leader of the cryogenic engineering team at FNAL. This work will primarily take place in year 1 of the proposal, with modest additional time required in outyears which is primarily support for assembly and installation tasks led by technicians.

The drafter(s) will support the work of the engineer(s) in the tasks listed above, and will be primarily responsible for the engineering drawings of all the systems above once the primary design work has been completed. In addition the drafter will be responsible for providing a complete solid model of the piping, and for providing drawing packages documenting the design and layout of the controls systems for the required safety documentation and reviews. The work schedule is similar in profile to that of the engineer.

This project will utilize SWBRL technicians to provide specialized technical support. The technicians will perform assembly tasks of the CAPTAIN cryogenic system, the CAPTAIN detector itself, and the controls and safety systems. In addition, the technician will support activities for installation of the detector, including the preparation work in the NuMI near detector hall and in the surface commissioning location. Much of this work will be done in collaboration with Fermilab technicians as needed because of their connection with the host laboratory and their familiarity with the underground areas at NuMI. The work will include cavern and surface site preparations, preparation of the adjacent parts of the MINERvA detector for the installation process, fabrication and assembly of support structures for CAPTAIN, installation of the TPC, sealing of the cryostat and final connections of the cryogenic system, assemble of the controls systems, filling the vessel and support for electronics and high voltage testing.

Specialized Service Facility: Research Support
The research support includes extensive administrative assistance required by this major project (as described in the 2 CFR 200) with coordinating budgets, working with multiple national labs, working with subcontractors travel, reporting required by DOE and Fermilab project management reviews, and inventory control for government owned property and equipment. Research support services are pooled with other departmental activities when possible to maximize financial efficacy, and costs are assigned are charged based on direct effort. The budget supports a fraction of two research support staff FTEs.

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Engineer/Drafter	$523,463	$ 24,544	$ 16,616			$ 564,623
Technician	$299,166	$164,353				$ 463,519
Research Operations Support	$ 18,250	$ 18,980	$ 7,463			$ 44,693
	$840,879	$207,877	$ 24,079	0	0	$1,072,835

9. Other: FNAL Purchase Order $20,260

A portion of our travel (some airfare, accommodations and car rental) costs are budgeted as standing purchase order with Fermi National Accelerator Laboratory (FNAL). This arrangement allows us to take advantage of national lab negotiated rates and purchasing power. Travel costs are detailed above in Section D. Travel.

G.	**TOTAL DIRECT COSTS**	**$2,622,379**
H.	**INDIRECT COSTS**	**$ 29,206**

MDTC off campus: 27.0% x $108,170 Base of Total Direct Costs = $29,206

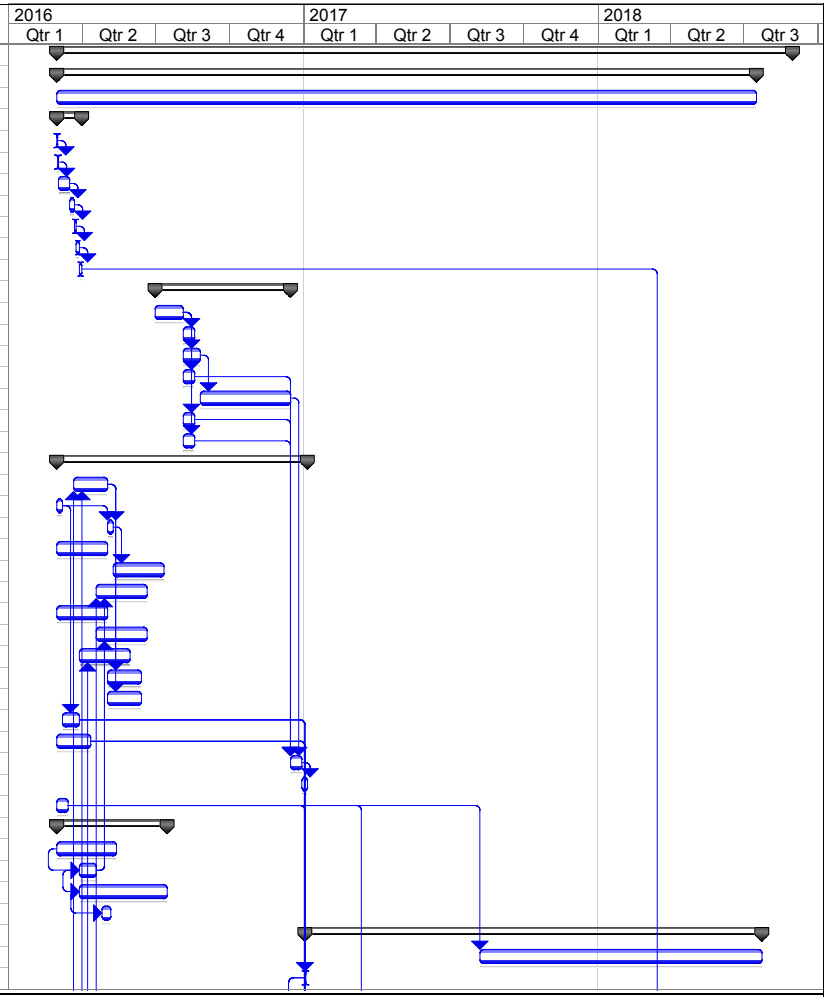
The F&A cost rates are the current rates negotiated with DHHS (agreement dated 6/16/15) with 27.0% off-campus MTDC for the budget period submitted. A copy of the agreement is attached. Note that F&A is incurred on the first $25,000 of subcontracts.

I.	**TOTAL DIRECT AND INDIRECT COSTS**	**$ 2,651,585**
J.	**FEE**	**$ 0**
K.	**TOTAL COST OF PROJECT**	**$ 2,651,585**

Supplement: Additional Detail on CAPTAIN MINERvA Project Cost and Schedule

The GANTT charts on the following three pages represent a technically driven schedule that has yet to have the final resources loaded. The tasks, durations and the level of effort needed during each task duration have been reviewed by Senior Engineers Keith Rielage and Barry Norris, of Los Alamos and Fermilab respectively. The durations and effort are then used in the budget estimates. The task dates are set to be as soon as possible in most cases, and do not reflect any constraints that would be imposed by the desire to minimize disruption to MINERvA data-taking (for example, installing CAPTAIN underground during a long accelerator maintenance shutdown). The table of costs for the individual tasks can be found after the GANTT charts.

ID	WBS	Task Name
1	**1**	**CAPTAIN-MINERvA Project**
2	**1.1**	**Project Administration**
3	1.1.1	Rochester financial admin (in lieu of ICR)
4	**1.2**	**Cavern Preparation Work at FNAL**
5	1.2.1	Clean Cavern Prior to Start
6	1.2.2	Remove Roof, supports, Cameras, alarms, VESDA
7	1.2.3	Empty helium target and warm up
8	1.2.4	Remove Veto walls
9	1.2.5	Remove He target vacuum pumps, water cooling, compressor
10	1.2.6	Remove target vent piping and top platform
11	1.2.7	Remove helium target and stand
12	**1.3**	**TPC Assembly**
13	1.3.1	Procure TPC Hardware
14	1.3.2	Support frame assembly
15	1.3.3	Wire-plane assembly
16	1.3.4	Field-cage assembly
17	1.3.5	Wire stringing
18	1.3.6	Cathode plane fabrication
19	1.3.7	Thermal baffle fabrication
20	**1.4**	**CAPTAIN Commissioning Preparation - Surface**
21	1.4.1	Design modifications for surface commissioning
22	1.4.2	Design of cable routing fixtures
23	1.4.3	Review of design including safety
24	1.4.4	Procure Indium Seals
25	1.4.5	Procure Cryostat Hardware
26	1.4.6	Procure Cabling
27	1.4.7	Procure PPE/Clean room gear
28	1.4.8	Procure Controls Hardware
29	1.4.9	Procure Cryocoolers and Peripherals
30	1.4.10	Fabrication of gas panel
31	1.4.11	Fabrication of cryo/gas piping
32	1.4.12	Fabrication of stand, cable-routing fixtures
33	1.4.13	Surface Hall Preparations
34	1.4.14	Packing equipment at LANL
35	1.4.15	Shipping to FNAL
36	1.4.16	Recieving and Inspection at FNAL
37	**1.4.17**	**Controls**
38	1.4.17.1	Engineer system and safety documents
39	1.4.17.2	Draft controls system
40	1.4.17.3	Fabricate controls
41	1.4.17.4	Electrician effort
42	**1.5**	**Assembly of CAPTAIN - Surface**
43	1.5.1	Engineering support for assembly activities
44	1.5.2	Place CAPTAIN on stand

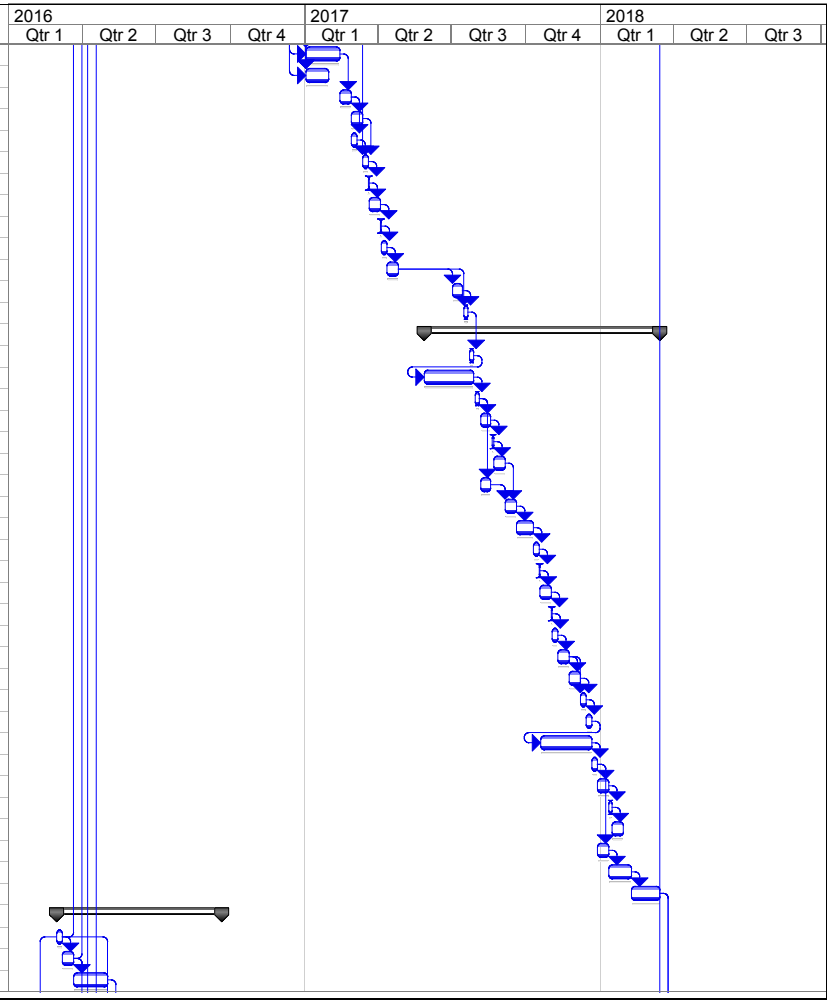


Project: CAPT-MINERvA-ProjPlan-V1_
Date: Tue 9/1/15

Task		Rolled Up Task		External Tasks	
Progress		Rolled Up Milestone		Project Summary	
Milestone		Rolled Up Progress		Group By Summary	
Summary		Split		Deadline	

Page 1

ID	WBS	Task Name
45	1.5.3	Assembly of TPC and electronics
46	1.5.4	Assembly of cryogenic and gas systems
47	1.5.5	Test Electronics and DAQ without HV
48	1.5.6	Mount and test the photon detection system
49	1.5.7	Mount and test HV continuity
50	1.5.8	Mount and align laser system
51	1.5.9	Move head into position without indium seal
52	1.5.10	Test DAQ in air
53	1.5.11	Test HV in air
54	1.5.12	Seal cryostat with indium
55	1.5.13	Final cabling of electronics
56	1.5.14	Final assembly of cryo/gas connections to cryostat
57	1.5.15	Align external laser to laser system on the cryostat
58	**1.6**	**CAPTAIN Commissioning - Surface**
59	1.6.1	Testing of HV in argon gas
60	1.6.2	Procure liquid argon
61	1.6.3	First argon fill
62	1.6.4	Test Electronics and DAQ in liquid argon without HV
63	1.6.5	Test HV in liquid argon
64	1.6.6	Test Electronics and DAQ in liquid argon with HV
65	1.6.7	Purify argon
66	1.6.8	Deploy laser calibration system
67	1.6.9	Warmup/disassemble if repairs needed
68	1.6.10	Re-mount and align laser system
69	1.6.11	Move head into position without indium seal
70	1.6.12	Retest DAQ in air
71	1.6.13	Retest HV in air
72	1.6.14	Re-seal cryostat with indium
73	1.6.15	Final cabling of electronics
74	1.6.16	Final assembly of cryo/gas connections to cryostat
75	1.6.17	Re-align external laser to laser system on the cryostat
76	1.6.18	Re-testing of HV in argon gas
77	1.6.19	Procure liquid argon
78	1.6.20	Second argon fill
79	1.6.21	Retest Electronics and DAQ in liquid argon without HV
80	1.6.22	Retest HV in liquid argon
81	1.6.23	Retest Electronics and DAQ in liquid argon with HV
82	1.6.24	Purify argon
83	1.6.25	Commissioning data collection
84	1.6.26	Decommission and disassemble for move Underground
85	**1.7**	**Engineeering Design for Underground**
86	1.7.1	Develop P&ID
87	1.7.2	Design vent stack
88	1.7.3	ODH calculations and review

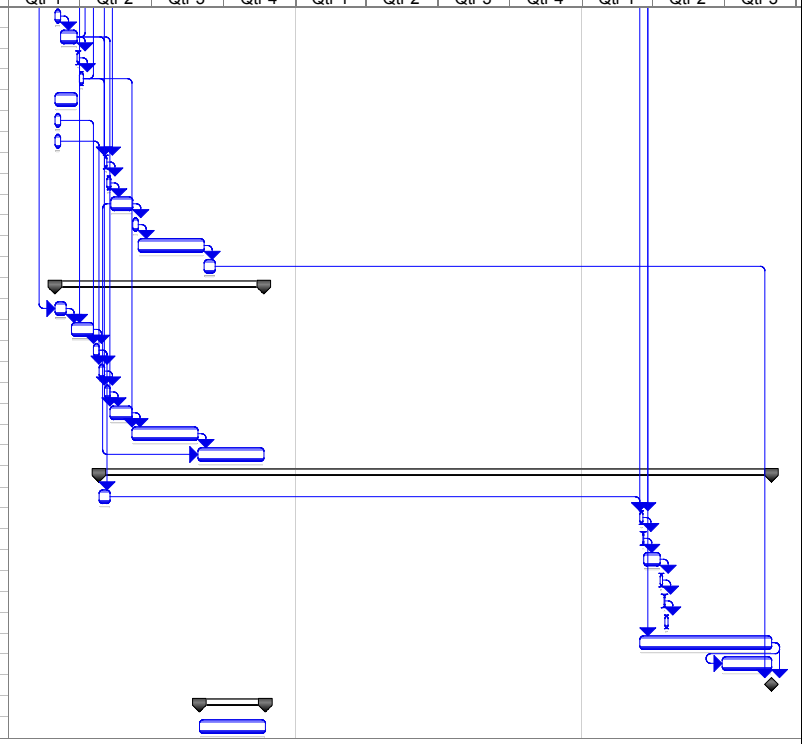


Project: CAPT-MINERvA-ProjPlan-V1_
Date: Tue 9/1/15

Task		Rolled Up Task		External Tasks	
Progress		Rolled Up Milestone		Project Summary	
Milestone		Rolled Up Progress		Group By Summary	
Summary		Split		Deadline	

Page 2

ID	WBS	Task Name
89	1.7.4	Design Heat exchangers for 600 Watt refrigerators
90	1.7.5	Design Manifold box for refrigerators
91	1.7.6	Size piping
92	1.7.7	Layout Equipment in Cavern
93	1.7.8	Pressure vessel note for Captain Vessel
94	1.7.9	Engineering note for Captain Support frame
95	1.7.10	Engineering note for TPC installation frame
96	1.7.11	Instrument and Valve summary
97	1.7.12	Operating Procedures
98	1.7.13	Piping Engineering notes
99	1.7.14	Size relief valves
100	1.7.15	Get approval for safety documents from CSS
101	1.7.16	ORC for cryo operations
102	**1.8**	**Drafting effort for Underground Work**
103	1.8.1	Draw P&ID
104	1.8.2	Draw Vent line
105	1.8.3	Draw Support Frame
106	1.8.4	Draw TPC Installation Frame
107	1.8.5	Draw Layout of equipment in Cavern
108	1.8.6	Draw up Refrigerator Manifold box
109	1.8.7	Solid model of piping and physical arangement
110	1.8.8	Piping fabrication Drawings
111	**1.9**	**Fabrication and Installation Underground**
112	1.9.1	Prefab support frame for Captain
113	1.9.2	Assemble support frame in Cavern
114	1.9.3	Bring Captain into Cavern
115	1.9.4	Prefab and install TPC maintenance frame
116	1.9.5	Install Detectors in Captain
117	1.9.6	Reposition vesssel on stand
118	1.9.7	Reinstall veto walls
119	1.9.8	Position and assemble new Cryo system
120	1.9.9	Procure liquid argon
121	1.9.10	Ready for Operations
122	**1.10**	**Computing**
123	1.10.1	Adaptataion of CAPTAIN MINERvA Software to FNAL Framework



Project: CAPT-MINERvA-ProjPlan-V1_
Date: Tue 9/1/15

Task		Rolled Up Task		External Tasks	
Progress		Rolled Up Milestone		Project Summary	
Milestone		Rolled Up Progress		Group By Summary	
Summary		Split		Deadline	

The costs for the individual tasks, unburdened, unescalated, and without contingency are given in the following table, This table includes costs that are part of the capital cost of the project as well as those which are not part of the capital cost of the project. Physicist labor is not costed.

WBS	Task Name	Unburdened Unescalated Base Cost
1.1	**Project Administration**	
1.1.1	Rochester financial admin (in lieu of ICR)	$31,000
1.2	**Cavern Preparation Work at FNAL**	
1.2.1	Clean Cavern Prior to Start	$3,145
1.2.2	Remove Roof, supports, Cameras, alarms, VESDA	$3,145
1.2.3	Empty helium target and warm up	$31,445
1.2.4	Remove Veto walls	$12,578
1.2.5	Remove HE target vacuum pumps, water cooling, compressor	$6,289
1.2.6	Remove target vent piping and top platform	$6,289
1.2.7	Remove helium target and stand	$9,434
1.3	**TPC Assembly**	
1.3.1	Procure TPC Hardware	$30,000
1.3.2	Support frame assembly	$18,573
1.3.3	Wire-plane assembly	$49,557
1.3.4	Field-cage assembly	$18,573
1.3.5	Wire stringing	$5,566
1.3.6	Cathode plane fabrication	$18,573
1.3.7	Thermal baffle fabrication	$5,566
1.4	**CAPTAIN Commissioning Preparation - Surface**	
1.4.1	Design modifications for surface commissioning	$42,355
1.4.2	Design of cable routing fixtures	$5,566
1.4.3	Review of design including safety	$19,993
1.4.4	Procure Indium Seals	$18,000
1.4.5	Procure Cryostat Hardware	$45,000
1.4.6	Procure Cabling	$10,000
1.4.7	Procure PPE/Clean room gear	$7,000
1.4.8	Procure Controls Hardware	$27,000
1.4.9	Procure Cryocoolers and Peripherals	$184,000
1.4.10	Fabrication of gas panel	$5,566
1.4.11	Fabrication of cryo/gas piping	$77,783
1.4.12	Fabrication of stand, cable-routing fixtures	$4,461
1.4.13	Surface Hall Preparations	$66,536
1.4.14	Packing equipment at LANL	$17,258
1.4.15	Shipping to FNAL	$29,643
1.4.16	Receiving and inspection at FNAL	$13,087

WBS	Task Name	Unburdened Unescalated Base Cost
1.4.17	**Controls**	
1.4.17.1	Engineer system and safety documents	$60,113
1.4.17.2	Draft controls system	$11,616
1.4.17.3	Fabricate controls	$71,565
1.4.17.4	Electrician effort	$0
1.5	**Assembly of CAPTAIN - Surface**	
1.5.1	Engineering support for assembly activities	$67,605
1.5.2	Place CAPTAIN cryostat on stand	$0
1.5.3	Assembly of TPC and electronics	$15,780
1.5.4	Assembly of cryogenic and gas systems	$0
1.5.5	Test Electronics and DAQ without HV	$7,890
1.5.6	Mount and test the photon detection system	$7,890
1.5.7	Mount and test HV continuity	$6,602
1.5.8	Mount and align laser system	$2,657
1.5.9	Move head into position without indium seal	$680
1.5.10	Test DAQ in air	$0
1.5.11	Test HV in air	$0
1.5.12	Seal cryostat with indium	$9,607
1.5.13	Final cabling of electronics	$0
1.5.14	Final assembly of cryo/gas connections to cryostat	$4,292
1.5.15	Align external laser to laser system on the cryostat	$0
1.6	**CAPTAIN Commissioning - Surface**	
1.6.1	Testing of HV in argon gas	$0
1.6.2	Procure liquid argon	$9,000
1.6.3	First argon fill	$8,714
1.6.4	Test Electronics and DAQ in liquid argon without HV	$6,124
1.6.5	Test HV in liquid argon	$3,156
1.6.6	Test Electronics and DAQ in liquid argon with HV	$10,069
1.6.7	Purify argon	$4,357
1.6.8	Deploy laser calibration system	$0
1.6.9	Warmup/disassemble if repairs needed (no cost)	$0
1.6.10	Re-Mount and align laser system	$2,657
1.6.11	Move head into position without indium seal	$680
1.6.12	Retest DAQ in air	$0
1.6.13	Retest HV in air	$0
1.6.14	Reseal cryostat with indium	$9,607
1.6.15	Final cabling of electronics	$0
1.6.16	Final assembly of cryo/gas connections to cryostat	$4,292

WBS	Task Name	Unburdened Unescalated Base Cost
1.6.17	Re-align external laser to laser system on the cryostat	$0
1.6.18	Re-testing of HV in argon gas	$0
1.6.19	Procure liquid argon	$9,000
1.6.20	Second Argon Fill	$8,714
1.6.21	Retest Electronics and DAQ in liquid argon without HV	$6,124
1.6.22	Retest HV in liquid argon	$3,156
1.6.23	Retest Electronics and DAQ in liquid argon with HV	$10,069
1.6.24	Purify argon	$4,357
1.7	**Engineering Design for Underground**	
1.7.1	Develop P&ID	$6,913
1.7.2	Design vent stack	$11,132
1.7.3	ODH calculations and review	$40,131
1.7.4	Design Heat exchangers for 600 Watt refrigerators (engineer)	$5,566
1.7.5	Design Manifold Box for Refrigerators	$16,698
1.7.6	Size piping	$3,340
1.7.7	Layout Equipment in Cavern	$3,340
1.7.8	Pressure vessel note for Captain Vessel	$39,986
1.7.9	Engineering note for Captain Support frame	$5,566
1.7.10	Engineering note for TPC installation frame	$5,566
1.7.11	Instrument and Valve summary	$4,687
1.7.12	Operating Procedures	$4,041
1.7.13	Piping Engineering notes	$28,999
1.7.14	Size relief valves	$6,913
1.7.15	Get approval for safety documents from CSS	$8,082
1.7.16	ORC for cryo operations	$13,469
1.8	**Drafting Effort for Underground Work**	
1.8.1	Draw P&ID	$7,744
1.8.2	Draw Vent line	$15,488
1.8.3	Draw Support Frame	$3,872
1.8.4	Draw TPC Installation Frame	$3,872
1.8.5	Draw Layout of equipment in Cavern	$3,872
1.8.6	Draw up Refrigerator Manifold box	$15,488
1.8.7	Solid model of piping and physical arangement	$46,464
1.8.8	Piping fabrication Drawings	$46,464
1.9	**Fabrication and Installation Underground**	
1.9.1	Prefab support frame for Captain	$25,506
1.9.2	Assemble support frame in Cavern	$6,289
1.9.3	Bring Captain into Cavern	$3,145
1.9.4	Prefab and install TPC maintenance frame	$47,168

WBS	Task Name	Unburdened Unescalated Base Cost
1.9.5	Install Detectors in Captain	$9,434
1.9.6	Reposition vesssel on stand	$3,145
1.9.7	Reinstall veto walls	$12,578
1.9.8	Install new vent line up the shaft	$247,648
1.9.9	Position and assemble new Cryo system	$189,968
1.9.10	Procure liquid argon	$9,000
1.10	**Computing**	
1.10.1	Design Integration of CAPTAIN+MINERvA Software to FNAL Framework	$58,646
	Total Base Cost (unescalated, unburdened)	**$2,149,572**

COLLEGES AND UNIVERSITIES RATE AGREEMENT

EIN: 1160743209A1

ORGANIZATION:
University of Rochester
206 Wallis Hall
P.O. Box 270026
Rochester, NY 14627

DATE:06/16/2015

FILING REF.: The preceding agreement was dated 04/09/2015

The rates approved in this agreement are for use on grants, contracts and other agreements with the Federal Government, subject to the conditions in Section III.

SECTION I: INDIRECT COST RATES

RATE TYPES: FIXED FINAL PROV. (PROVISIONAL) PRED. (PREDETERMINED)

	EFFECTIVE PERIOD				
TYPE	**FROM**	**TO**	**RATE(%)**	**LOCATION**	**APPLICABLE TO**
PRED.	07/01/2014	06/30/2017	53.50	On-Campus	Research
PRED.	07/01/2017	06/30/2019	54.00	On-Campus	Research
PRED.	07/01/2014	06/30/2015	26.60	Off-Campus	Research
PRED.	07/01/2015	06/30/2019	27.00	Off-Campus	Research
PRED.	07/01/2014	06/30/2015	33.50	On-Campus	Other Sponsored Activities
PRED.	07/01/2015	06/30/2019	35.00	On-Campus	Other Sponsored Activities
PRED.	07/01/2014	06/30/2015	24.80	Off-Campus	Other Sponsored Activities
PRED.	07/01/2015	06/30/2019	25.00	Off-Campus	Other Sponsored Activities
PROV.	07/01/2019	Until Amended			Use same rates and conditions as those cited for fiscal year ending June 30, 2019.

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*BASE

Modified total direct costs, consisting of all direct salaries and wages, applicable fringe benefits, materials and supplies, services, travel and up to the first $25,000 of each subaward (regardless of the period of performance of the subawards under the award). Modified total direct costs shall exclude equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs and the portion of each subaward in excess of $25,000. Other items may only be excluded when necessary to avoid a serious inequity in the distribution of indirect costs, and with the approval of the cognizant agency for indirect costs.

ORGANIZATION: University of Rochester

AGREEMENT DATE: 6/16/2015

SECTION I: FRINGE BENEFIT RATES**

TYPE	FROM	TO	RATE(%)	LOCATION	APPLICABLE TO
FIXED	7/1/2014	6/30/2015	28.60	All (A)	F/T Fac. Senior Adm
FIXED	7/1/2014	6/30/2015	35.30	All (B)	Prof Adm & Sup&Secr
FIXED	7/1/2014	6/30/2015	10.30	All	Visit Fac & TAR
FIXED	7/1/2014	6/30/2015	26.70	All	PD,Int&Res,Instr&Fel
FIXED	7/1/2014	6/30/2015	60.20	All (B)	Union-1199 Barg Unit
FIXED	7/1/2014	6/30/2015	11.10	All	Summer Compensation
FIXED	7/1/2015	6/30/2016	28.00	All (A)	F/T Fac. Senior Adm
FIXED	7/1/2015	6/30/2016	33.60	All (B)	Prof Adm & Sup&Secr
FIXED	7/1/2015	6/30/2016	11.00	All	Visit Fac & TAR
FIXED	7/1/2015	6/30/2016	23.10	All	PD,Int&Res,Instr&Fel
FIXED	7/1/2015	6/30/2016	59.20	All (B)	Union-1199 Barg Unit
FIXED	7/1/2015	6/30/2016	10.20	All	Summer Compensation
PROV.	7/1/2016	Until amended	29.10	All (A)	F/T Fac. Senior Adm
PROV.	7/1/2016	Until amended	35.30	All (B)	Prof Adm & Sup&Secr
PROV.	7/1/2016	Until amended	10.80	All	Visit Fac & TAR
PROV.	7/1/2016	Until amended	26.00	All	PD,Int&Res,Instr&Fel
PROV.	7/1/2016	Until amended	59.00	All (B)	Union-1199 Barg Unit

PROV.	7/1/2016	Until amended	13.00 All	Summer Compensation

** DESCRIPTION OF FRINGE BENEFITS RATE BASE:

(A) See Special Remarks - 3, 4
(B) See Special Remarks - 4

SECTION II: SPECIAL REMARKS

TREATMENT OF FRINGE BENEFITS:

The fringe benefits are charged using the rate(s) listed in the Fringe Benefits Section of this Agreement. The fringe benefits included in the rate(s) are listed below.

TREATMENT OF PAID ABSENCES

Vacation, holiday, sick leave pay and other paid absences are included in salaries and wages and are claimed on grants, contracts and other agreements as part of the normal cost for salaries and wages. Separate claims are not made for the cost of these paid absences.

1. Equipment means an article of nonexpendable, tangible personal property having a useful life of more than one year, and an acquisition cost of $1,000 or more per unit.

2. Grants or contracts will not be subject to more than one F&A cost rate. If more than 50% of a project is performed off-campus, the off-campus rate will apply to the entire project.

3. Institution has a decreasing rate structure for salaries above $118,500 on file in their office which is not published as part of this agreement. The approved rate structure list can be accessed at: http://www.rochester.edu/orpa/proposals/fringe/

4. The fringe benefit costs listed below are reimbursed to the grantee through the direct fringe benefit rate: Pension/Annuities, Health and Dental Insurance, Disability Insurance, Tuition Aid/Reimbursement (Employee only & only University of Rochester tuition), Travel Insurance, Social Security Taxes (FICA), Separation/Vacation Pay, Workers Compensation, Other Compensation, Faculty Early Retirement, Employees Assistance Program, Retirees Health/Dental Coverage, Staff Benefits Admin, Life Insurance, Family Care Program, NUHHCE Union Benefits, Extended Sick Pay, Occupational Health, Env. Health and Safety, and Leave of Absence.

SECTION III: GENERAL

A. LIMITATIONS:

The rates in this Agreement are subject to any statutory or administrative limitations and apply to a given grant, contract or other agreement only to the extent that funds are available. Acceptance of the rates is subject to the following conditions: (1) Only costs incurred by the organization were included in its facilities and administrative cost pools as finally accepted: such costs are legal obligations of the organization and are allowable under the governing cost principles; (2) The same costs that have been treated as facilities and administrative costs are not claimed as direct costs; (3) Similar types of costs have been accorded consistent accounting treatment; and (4) The information provided by the organization which was used to establish the rates is not later found to be materially incomplete or inaccurate by the Federal Government. In such situations the rate(s) would be subject to renegotiation at the discretion of the Federal Government.

B. ACCOUNTING CHANGES:

This Agreement is based on the accounting system purported by the organization to be in effect during the Agreement period. Changes to the method of accounting for costs which affect the amount of reimbursement resulting from the use of this Agreement require prior approval of the authorized representative of the cognizant agency. Such changes include, but are not limited to, changes in the charging of a particular type of cost from facilities and administrative to direct. Failure to obtain approval may result in cost disallowances.

C. FIXED RATES:

If a fixed rate is in this Agreement, it is based on an estimate of the costs for the period covered by the rate. When the actual costs for this period are determined, an adjustment will be made to a rate of a future year(s) to compensate for the difference between the costs used to establish the fixed rate and actual costs.

D. USE BY OTHER FEDERAL AGENCIES:

The rates in this Agreement were approved in accordance with the authority in Title 2 of the Code of Federal Regulations, Part 200 (2 CFR 200), and should be applied to grants, contracts and other agreements covered by 2 CFR 200, subject to any limitations in A above. The organization may provide copies of the Agreement to other Federal Agencies to give them early notification of the Agreement.

E. OTHER:

If any Federal contract, grant or other agreement is reimbursing facilities and administrative costs by a means other than the approved rate(s) in this Agreement, the organization should (1) credit such costs to the affected programs, and (2) apply the approved rate(s) to the appropriate base to identify the proper amount of facilities and administrative costs allocable to these programs.

BY THE INSTITUTION:

University of Rochester

(INSTITUTION)

(SIGNATURE)

DOUGLAS W. WYLIE

(NAME)

ASSOCIATE VP FOR FINANCIAL OPERATIONS & UNIVERSITY CONTROLLER

(TITLE)

6/23/2015

(DATE)

ON BEHALF OF THE FEDERAL GOVERNMENT:

DEPARTMENT OF HEALTH AND HUMAN SERVICES

(AGENCY)

Darryl W. Mayes -S

Digitally signed by Darryl W. Mayes -S
DN: c=US, o=U.S. Government, ou=HHS, ou=PSC, ou=People, 0.9.2342.19200300.100.1.1=2000131669, cn=Darryl W. Mayes -S
Date: 2015.06.19 09:27:11 -04'00'

(SIGNATURE)

Darryl W. Mayes

(NAME)

Deputy Director, Cost Allocation Services

(TITLE)

6/16/2015

(DATE) 0943

HHS REPRESENTATIVE: Michael Leonard

Telephone: (212) 264-2069

Components of Published Facilities and Administrative Cost Rate

Institution: **University of Rochester**
FY Covered by Rate: **Fiscal Years Ending 6/30/15 to 6/30/19**
Predetermined Rates

Rate Component	FY 15-17	FY 18-19
1. a. Depreciation - Bldgs & Improvements	4.80%	5.00%
b. Depreciation - Equipment	2.10%	2.10%
2. Interest	3.30%	3.30%
3. Operation & Maintenance	15.00%	15.30%
4. General Administration	0.00%	0.00% *
5. Departmental Administration	24.00%	24.00% *
6. Sponsored Projects Administration	0.00%	0.00% *
7. Library	3.00%	3.00%
8. Utility Allowance	1.30%	1.30%
Published On-Campus Rate - Research	**53.5%**	**54.0%**

*** Reflects provisions of Appendix III to Part 200 of Uniform Guidance—Indirect (F&A) Costs Identification and Assignment, and Rate Determination for Institutions of Higher Education (IHEs), C.8. dated December 26, 2013.**

Name : DOUGLAS W. WYLIE

Title: ASSOCIATE VP FOR FINANCIAL OPERATIONS AND UNIVERSITY CONTROLLER

Date: 6/23/2015

Components of Published Facilities and Administrative Cost Rate

Institution: University of Rochester
FY Covered by Rate: Fiscal Years Ending 6/30/15 to 6/30/19
Predetermined Rates

Rate Component	FY 15	FY 16-19
1. a. Depreciation - Bldgs & Improvements	1.90%	2.30%
b. Depreciation - Equipment	0.50%	0.50%
2. Interest	0.70%	0.70%
3. Operation & Maintenance	4.70%	5.80%
4. General Administration	0.00%	0.00% *
5. Departmental Administration	24.00%	24.00% *
6. Sponsored Projects Administration	0.00%	0.00% *
7. Library	1.70%	1.70%
8. Other		
Publish.On-Campus Rate - Oth. Spons. Act.	**33.5%**	**35.0%**

*** Reflects provisions of Appendix III to Part 200 of Uniform Guidance—Indirect (F&A) Costs Identification and Assignment, and Rate Determination for Institutions of Higher Education (IHEs), C.8. dated December 26, 2013.**

Name : DOUGLAS W. WYLIE

Title: ASSOCIATE VP FOR FINANCIAL OPERATIONS AND UNIVERSITY CONTROLLER

Date: 6/23/2015

Components of Published Facilities and Administrative Cost Rate

Institution: University of Rochester
FY Covered by Rate: Fiscal Years Ending 6/30/15 to 6/30/19
Predetermined Rates

Rate Component	FY 15	FY 16-19
1. a. Depreciation - Bldgs & Improvements	0.00%	0.00%
b. Depreciation - Equipment	0.00%	0.00%
2. Interest	0.00%	0.00%
3. Operation & Maintenance	0.00%	0.00%
4. General Administration	0.00%	0.00% *
5. Departmental Administration	24.00%	24.00% *
6. Sponsored Projects Administration	0.00%	0.00% *
7. Library	2.60%	3.00%
8. Other		
Published Off-Campus Rate - Research	**26.6%**	**27.0%**

*** Reflects provisions of Appendix III to Part 200 of Uniform Guidance—Indirect (F&A) Costs Identification and Assignment, and Rate Determination for Institutions of Higher Education (IHEs), C.8. dated December 26, 2013.**

Name : DOUGLAS W. WYLIE

Title: ASSOCIATE VP FOR FINANCIAL OPERATIONS AND UNIVERSITY CONTROLLER

Date: 6/23/2015

Components of Published Facilities and Administrative Cost Rate

Institution: University of Rochester
FY Covered by Rate: Fiscal Years Ending 6/30/15 to 6/30/19
Predetermined Rates

Rate Component	FY 15	FY 16-19
1. a. Depreciation - Bldgs & Improvements	0.00%	0.00%
b. Depreciation - Equipment	0.00%	0.00%
2. Interest	0.00%	0.00%
3. Operation & Maintenance	0.00%	0.00%
4. General Administration	0.00%	0.00% *
5. Departmental Administration	24.00%	24.00% *
6. Sponsored Projects Administration	0.00%	0.00% *
7. Library	0.80%	1.00%
8. Other		
Published Off-Campus Rate - Oth. Spons. Act.	**24.8%**	**25.0%**

*** Reflects provisions of Appendix III to Part 200 of Uniform Guidance—Indirect (F&A) Costs Identification and Assignment, and Rate Determination for Institutions of Higher Education (IHEs), C.8. dated December 26, 2013.**

Name : DOUGLAS W. WYLIE

Title: ASSOCIATE VP FOR FINANCIAL OPERATIONS AND UNIVERSITY CONTROLLER

Date: 6/23/2015