CAPTAIN, NuMI and Low Energy Physics Programs*

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Abstract

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). The CAPTAIN detector is a portable and evacuable cryostat that can hold 7700 liters of liquid argon. Within the CAPTAIN program a prototype detector has been built, Mini-CAPTAIN a smaller liquid argon TPC inside a 1500 liter cryostat. We present the CAPTAIN physics program that includes measuring neutron interactions at Los Alamos Neutron Science Center, the proposal for measuring neutrino interactions at the NuMI (Neutrinos from Main Injector) beamline at energies relevant for DUNE, and the potential for low-energy neutrino measurements at the Booster Neutrino Beam (BNB) and the NuMI absorber. Finally we discuss the status of CAPTAIN and the first demonstration of an ionization track from a laser calibration system in the Mini-CAPTAIN detector, announced in August 2015.

INTRODUCTION

Precise measurements of neutrino cross-sections and nuclear effects are needed in order to have a complete understanding of neutrino oscillations because the neutrino oscillation probability is energy-dependent, the reconstruction of the incoming neutrino energy becomes critical. In addition, there is a consensus that more and precise neutrino cross-section measurements are needed to constrain theoretical models. These are necessary to develop a coherent plan that would contribute to the success of future oscillation measurements. As an example the Deep Underground Neutrino Experiment (DUNE) has proposed to use a liquid argon time project chamber (TPC) detector with a baseline of 1300 km from the Long-Baseline Neutrino Facility (LBNF), which will provide a high-power, wide-band muon neutrino beam [1], and measurements of neutrino-argon interactions in this energy range are crucial for the success of the DUNE. Results on neutrino-argon interactions have been released from ArgoNeuT experiment [3–6] a 170 liter (0.25 ton active volume) liquid argon TPC that took data in the NuMI low-energy beam configuration however these results are statistically limited.

CAPTAIN NUMI PHYSICS PROGRAM

Liquid argon TPCs provide excellent position resolution, energy resolution, and particle identification, enabling precision reconstruction of complex interaction topologies. The CAPTAIN TPC is a hexagonal shape with a 1 m height and 2 m diameter, consisting of three active wire planes with 3 mm pitch and 3 mm wire spacing on a cathode plane, grid plane, and ground plane. CAPTAIN will be equipped with a photon detection system to observe scintillation light produced inside the liquid argon.

To address the studies important for neutrino oscillations, the study of neutrino-argon interactions in the neutrino energy range relevant for long-baseline neutrino oscillation physics is needed. Hence CAPTAIN is designed to conduct studies important for precision measurements of neutrino oscillations and observation of supernova burst neutrinos in a next generation liquid argon neutrino detector.

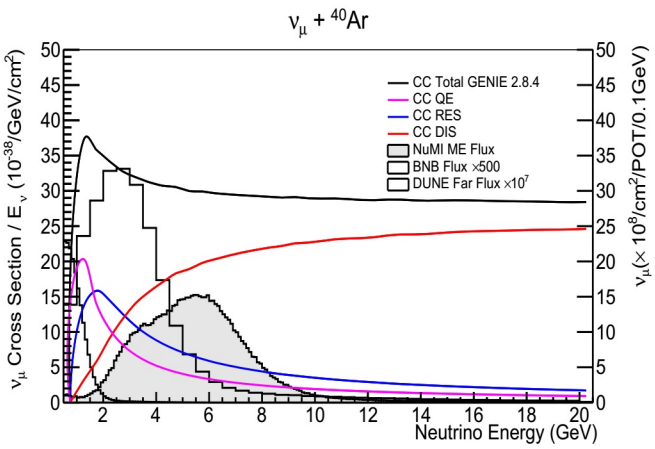

FIG. 1: Unoscillated ν_μ DUNE far flux, BNB flux at MiniBooNE, medium-energy NuMI flux at the MINOS near hall and GENIE cross section on 40Ar.

Figure 1 compares the neutrino flux from the medium-energy NuMI beam at the MINOS near hall, the flux from the Booster Neutrino Beam (BNB) at the location of MiniBooNE, and the proposed flux for DUNE at the DUNE far detector. The NuMI beam medium-energy (ME) configuration overlaps the entire neutrino energy range for DUNE. By placing CAPTAIN in the NuMI beamline there is an opportunity to study neutrino-argon interactions in the neutrino energy range relevant for DUNE's long-baseline neutrino oscillation physics program.

MINERvA is an experiment dedicated to measuring neutrino cross-sections located at the MINOS near hall, in front of the MINOS near detector (ND) and is currently taking data in the NuMI ME configuration. The MINERvA detector consists of a series of nuclear targets followed by a fine-grained scintillator tracking region surrounded by electromagnetic and hadronic calorimeters [7]. The magnetized MINOS ND serves as a downstream muon spectrometer. MINERvA's dataset includes interactions on a variety of nuclei ranging from helium to lead. Combining CAPTAIN and MINERvA would be very beneficial in order to study neutrino-argon interactions in the energy range relevant for long-baseline neutrino oscillation physics, because some particles exiting CAPTAIN, most importantly forward-going muons, can be tracked and their energy measured in MINERvA 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. The simplest way to integrate the CAPTAIN detector into MINERvA is to replace MINERvA's existing liquid helium target with the CAPTAIN detector, and this is our default plan. We performed simulations of neutrino interactions on liquid argon with the CAPTAIN detector geometry placed in the position of MINERvA's existing liquid helium target with the on-axis ME NuMI flux. The simulations predict 12.5M ν_μ CC interactions within the CAPTAIN LAr volume for an exposure of 6×10^{20} protons on target (POT). To study the acceptance of ν_μ CC events in MINERvA and the MINOS ND, neutrino interactions were generated using GENIE Neutrino Monte Carlo Generator [8] version 2.8.4. MINERvA's detector response was simulated with a tuned GEANT4-based simulation. Considering muons that reach MINERvA or the MINOS ND, the overall muon reconstruction efficiency for ν_μ CC events is 64%. Figure 2 shows the muon acceptance as a function of neutrino energy, muon momentum, Q^2 and muon angle with respect to the beam direction. In addition, Figure 2 shows the events where the muon charge sign is reconstructed; this is particularly important for an antineutrino flux configuration to avoid wrong sign contamination. In terms of topologies we expect to collect 916k CCQE-like events, 1953k CC1π events and 1553k CC1π^0 [9]. Finally it is important to mentioned that CAPTAIN-MINERvA will have the unique ability to study event reconstruction for neutrino interactions on argon events with different particle multiplicities and will be the only experiment making high-statistics measurements

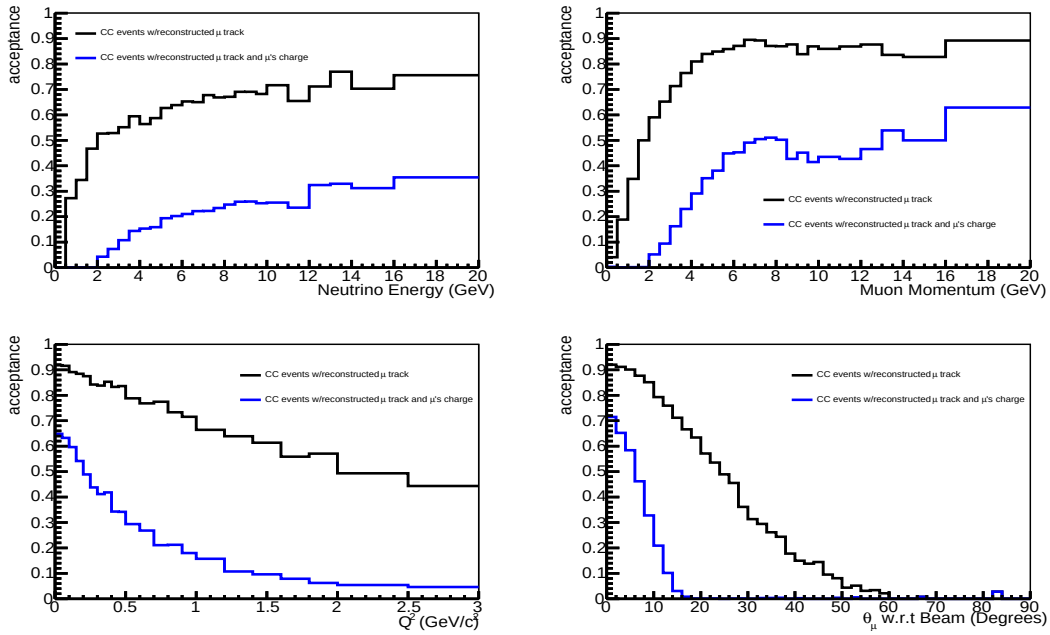

FIG. 2: Muon acceptance for ν_μ CC events as function of neutrino energy, muon momentum, Q2 and muon angle with respect to the beam direction for all events with a reconstructed muon track (black) and for the subset of events with reconstructed tracks in which the charge sign is also reconstructed (blue).

of neutrino interactions on argon in the medium energy range before DUNE.

CAPTAIN LOW ENERGY PHYSICS PROGRAM

Measurement of supernova neutrinos (SN) is also an important physics topic for the DUNE experiment [1]. The measurement of the time evolution of the energy and flavor spectrum of neutrinos from supernova can revolutionize our understanding of neutrino properties and SN physics. In order to achieve such measurements it is very important to reject neutron spallation backgrounds. Therefore, it is crucial to have a reliable method to tag neutron-argon interactions. This will also help to improve the neutrino energy reconstruction for neutrino oscillation measurements when neutrons are produced in the final state from the neutrino-argon interaction. The CAPTAIN low energy physics program plans to perform neutron studies at the Weapons Neutron Research Facility (WNR) at LANL. The project plans to place the Mini-CAPTAIN detector in the WNR neutron beam. The

Mini-CAPTAIN detector is a smaller liquid argon TPC inside a 1500 liter cryostat. The CAPTAIN detector and the Mini-CAPTAIN detector are similar, including cryostats, cryogenics, electronics, TPCs, photon detection system and laser calibration system. The design differences between the two detectors are driven by the cryostat sizes and geometries.

During the neutron run at the WNR two runs have been proposed, high-intensity and low-intensity run. The high-intensity run is useful to study neutron production of Cl isotopes that constitute an important background for SN neutrino detection. The low-intensity mode can be used to study the neutrino-like argon reaction: $n+^{40}Ar \rightarrow^{40} Ar^{*}+n$. Since this interaction is a very good control sample for the neutral-current (NC) interactions, $\nu_x +^{40} Ar \rightarrow^{40} Ar^{*} + \nu_x$, induced by supernova neutrinos and to study reconstruction capabilities of $^{40}Ar^{*}$ de-excitation in a LAr TPC.

In addition, as part of the coherent plan relevant for the success of DUNE, it is necessary to understand neutrino-argon interactions at low energies (tens of MeV) in order to demonstrate the capability of a liquid argon detector to search SN neutrinos. The $\nu - Ar$ cross-section has never been measured for these energies and have theoretical uncertainties around 10-15%. To measure low-energy neutrino-argon interaction we plan to put the CAPTAIN detector close to the target hall at the Booster Neutrino Beam at Fermilab to collect low-energy neutrinos produced by pions that decay at rest. Detailed beam flux studies are underway and require neutron background measurements from SciBath [10] to determine the ideal location and necessary shielding.

Another source for a low-energy neutrino beam is at the NuMI absorber hall. Studies are underway which include a more detailed NuMI flux simulation, measurements of backgrounds in the access tunnel and determination of the amount of shielding.

SUMMARY AND CAPTAIN STATUS

The CAPTAIN cryostat, electronics and field cage are in hand to construct the CAPTAIN detector. Also, the purification system has been delivered. CAPTAIN is currently planned to move to Fermilab by Fall 2016.

The cryostat, cryogenics and TPC of the Mini-CAPTAIN detector have been commissioned. The electronics, TPC and heat load have been tested. The purity monitor is installed and photon detector system will be installed soon. Purification tests for Mini-CAPTAIN

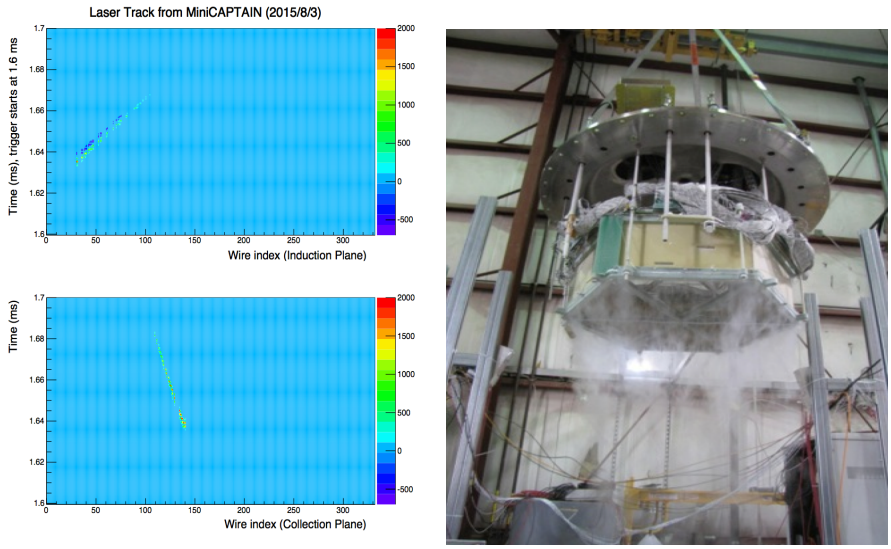

FIG. 3: First laser track observed by the Mini-CAPTAIN TPC on August 3, 2015. The color represents ADC value (left). Mini-Captain Assembly (right).

have been under way since July 2015. On August 3, 2015, the first ionization track from the laser calibration system was observed by the Mini-CAPTAIN TPC. The first image of a UV laser track recorded by a induction and collection plane of the TPC is shown in Figure 3 (left). The observation of the first track demonstrates that the required purity has been achieved. Commissioning of the Mini-CAPTAIN detector is reaching completion and its neutron beam running at WNR will take place in January 2016.

CAPTAIN measurements will provide great benefit to the neutrino oscillation and supernova neutrino programs at DUNE, therefore CAPTAIN will play a significant role to the DUNE R&D program. A full proposal to Fermilab PAC for the CAPTAIN-MINERvA project has been submitted.

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