# 10th International Neutrino Summer School 2017 - REGISTRATION

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# Book of Abstracts

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## Measurement of Reconstructed Charged Particle Multiplicities of Neutrino Interactions in MicroBooNE

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We compare the observed charged particle multiplicity distributions in the MicroBooNE liquid argon time projection chamber from neutrino interactions in a restricted final state phase space to predictions of this distribution from several GENIE models. The measurement uses a data sample consisting of neutrino interactions with a final state muon candidate fully contained within the MicroBooNE detector. These data were collected in 2015-2016 with the Fermilab Booster Neutrino Beam (BNB), which has an average neutrino energy of 800 MeV, using an exposure corresponding to 5e19 protons-on-target. The analysis employs fully automatic event selection and charged particle track reconstruction and uses a data-driven technique to determine the contribution to each multiplicity bin from neutrino interactions and cosmic-induced backgrounds. The restricted phase space employed makes the measurement most sensitive to the higher-energy charged particles expected from primary neutrino-argon collisions and less sensitive to lower energy protons expected to be produced in final state interactions of collision products with the target argon nucleus.

**1**

## Measurement of gamma-rays from neutron-oxygen reaction for neutrino-nucleus interaction

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Precise knowledge of the neutrino neutral current quasielastic interaction cross section is important for several physics searches at Super-Kamiokande. For example, it is necessary to understand the background accurately in searches for supernova relic neutrinos and dark matter. At the T2K experiment the cross section has been measured but systematic errors are large. This is because neutrino interactions often produce nucleons whose subsequent gamma-ray production on oxygen is currently not well understood. Super-K and T2K must rely on models based on little data. In order to improve these models, measurements of gamma-ray production with a quasi-mono energetic neutron beam and water target have started at Osaka University's Research Center for Nuclear Physics. Gamma-ray measurements were made with a germanium detector and a LaBr3(Ce) scintillator. In addition, the neutron flux was measured in order to estimate the gamma-ray production cross section. So far three experiments have been carried out with 80 MeV and 392 MeV (kinetic energy) neutrons, and 6.13 MeV gamma-rays were observed that are not currently modeled well in Super-K simulations. In this poster, these measurements and gamma-ray production cross section results will be presented.

**2**

## Super-K Gd Project: Detecting Anti-neutrinos from Pre-supernova Stars

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Prior to a core collapse supernovae, progenitor stars contract and increase in temperature, fusing higher mass elements up to iron. The increase in temperature leads to an increase in the flux and

energy of antineutrinos, mainly via pair production, over short timescales. SK-Gd will be able to separate antineutrino candidates by tagging neutron capture on gadolinium, and would see an increase in the rate of antineutrino candidates hours or days prior to the core collapse of a nearby star. In the case of Betelgeuse, there may be several days warning. This could be used to alert astronomers and prevent unfortunate detector dead-time in the case of a nearby supernova, and could probe stellar fusion beyond He. Investigations in to the sensitivity of this technique at SK-Gd are presented.

**3**

# Liquid Scintillator Purity Investigation For the Jiangmen Underground Neutrino Observatory

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The Jiangmen Underground Neutrino Observatory (JUNO) is a 20 kt liquid scintillator reactor neutrino experiment currently being built near the town of Kaiping in the Guangdong province in southern China. In order to reliably reconstruct neutrino-induced inverse beta decay events from photomultiplier signals, the scattering properties of the detector materials need to be sufficiently well known. In the LAB-based liquid scintillator that will be used in JUNO, the primary contribution to the scattering process comes from Rayleigh scattering. This poster will detail the experimental approach to obtain the characteristic Rayleigh scattering length in an optical laboratory setup. Furthermore, air leaks in the filling and cycling lines or failures of the purification plants are potential risks that endanger the high radiopurity imperative to obtain clean signals within such a large active target volume. The OSIRIS pre-detector was envisioned as a failsafe monitor to assess the quality of the scintillator batches before filling them into the central detector. A Monte Carlo simulation that served as a feasibility study and investigated the sensitivity limits of such a system will be presented.

**4**

# Novel Application of Non-parametric Density Estimation Techniques in Muon Ionization Cooling Experiment

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The aim of the international Muon Ionization Cooling Experiment (MICE) is to demonstrate muon beam cooling for the first time. When muons are produced from pion decay, they occupy a large volume in the position-momentum phase space and the process of reducing their volume is known as beam cooling. Ionization cooling is the only beam cooling technique fast enough to be used for muons within their short lifetime. Ionization cooling occurs when the beam loses momentum while traversing an absorbing material. In MICE, commonly used figures of merit for cooling are the beam emittance reduction, the phase-space volume reduction, and the phase-space density increase. Emittance is the measure of the size of the beam, and with a reduced beam emittance or phase-space volume, more muons can fit in a smaller aperture of a cost-effective accelerator. This may enable the construction of future high-intensity muon accelerators, such as a Neutrino Factory or a Muon Collider. To demonstrate transverse beam cooling, MICE uses two scintillating-fiber tracking detectors, immersed in the constant magnetic fields of Spectrometer Solenoid modules. These trackers, one upstream and one downstream of the absorber reconstruct and measure the position and momentum coordinates of individual muons, and the absorber provides the ionization energy loss required for beam cooling. Given the precision with which MICE aims to demonstrate beam cooling, it is necessary to develop analysis tools that can account for any effects which may lead to inaccurate cooling measurements. The non-parametric density estimation techniques are analysis tools that are robust against these effects and measure the muon beam phase-space density and volume. In this study, two density estimation techniques, the kernel density estimation (KDE) and kernel-based nearest neighbor density estimation (NNDE) methods are investigated.

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## Searches for Heavy Sterile Neutrinos in MicroBooNE

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Heavy sterile neutrinos with a mass between 1 and 493 MeV may be produced by the decay of kaons and pions in the decay volume of BNB and NuMI. These neutrinos would then travel to the MicroBooNE detector where they would decay in-flight and produce visible particles that would provide a striking signature in the liquid-argon Time Projection Chamber of the MicroBooNE experiment comprising either two electromagnetic showers or a track and an electromagnetic shower. In this work we analyze MicroBooNE data and search for heavy sterile neutrino decays, results from this search could either prove discovery or place new limits on the active-sterile neutrino mixing parameter space.

**6**

## From energy deposition to raw data: the journey of ionization charge in a dual phase LAr TPC

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The Liquid Argon Time Projection Chamber (LAr TPC) is the state-of-the-art technology for large-scale neutrino detectors. Charged particles ionize the argon atoms and create scintillation and Cherenkov light. While the light is collected by PMT's, the ionization charge is drifted towards the charge readout in a high electric field, slowly losing in strength due to impurities in the argon. In the attempt to maximize the drift distance by increasing the signal-to-noise ratio, the WA105 collaboration is developing a dual phase LAr TPC. In this type of detector, the charge is extracted from the liquid argon into a gas argon layer, where it is amplified in a Large Electron Multiplier (LEM) before it reaches the charge readout. For the analysis of the measured waveforms, a good understanding of the following processes is crucial: diffusion and attenuation during the drift in liquid argon, delays in the extraction process, amplification inside the LEM's and the response of the charge sensitive preamplifier.

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## "First results from the CUORE experiment"

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The CUORE - Cryogenic Underground Observatory for Rare Events - experiment hosted at Gran Sasso National Laboratories in Italy is a ton-scale cryogenic experiment designed for the search for neutrinoless double beta ($0\nu\beta\beta$) decay of 130Te. It consists of an array of 988 bolometric TeO2 crystals ($5\times5\times5$ cm3 each) operated at $\sim$10 mK arranged in 19 towers. The CUORE commissioning has been completed in August 2016. It was followed by the detector cooldown and pre-operation runs for detectors optimization; CUORE began taking physics data in the spring of 2017. In this poster we will present the detector characterization, the cryostat and bolometers performances during the pre-operation runs and the noise reduction techniques to obtain the optimal sensitivity in the region of interest for the $0\nu\beta\beta$ decay in130Te. Moreover it will be shown the outcome of the analysis of early physics data from the experiment.

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## Constraining the T2K Neutrino Flux with NA61/SHINE 2009 Replica Target Data

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T2K (Tokai-to-Kamioka) is a long-baseline neutrino oscillation experiment comprising of the J-PARC neutrino beamline, a near detector complex (ND280) and a far detector (Super-Kamiokande), located 295 km away from J-PARC.
One of the dominant T2K systematics is the neutrino flux error. Neutrinos are created through decays of unstable hadrons produced by interactions of 31 GeV/c protons in a long graphite target (90 cm). Accurate modelling of hadronic interactions inside the long target is challenging but crucial as the collaboration prepares for entering the regime of high precision neutrino oscillation measurements. Constraining the neutrino flux allows a better understanding of neutrino interactions at the near and far detectors.
T2K uses several external hadron production measurements for re-weighting the neutrino flux prediction. The re-weighting primarily relies on NA61/SHINE data for interactions of protons incident on a thin graphite target (2 cm). This analysis uses a new NA61 dataset, collected in 2009 using the full length (90 cm) replica of the T2K target. Combined with a new flux re-weighting technique, the preliminary results suggest a reduction of the neutrino flux error by around 50%, from 9% to less than 5% fractional uncertainty.

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## Tagging Gammas in Reconstructed Neutrino Interactions

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When neutrinos interact with liquid Argon, ionized electrons and de-excitation gammas are produced. Once the ionized electrons decelerate, the kinetic energy lost is converted into bremsstrahlung gammas. In principle, neutral current neutrino interactions should only release de-excitation gammas; charged current neutrino interactions should contain de-excitation gammas and ionized electrons that produce bremsstrahlung gammas; and interactions where neutrinos elastically scatter on electrons should only contain bremsstrahlung gammas. It would be a useful ability to separate those events into their respective categories, particularly for low-energy neutrinos released in a supernova burst. Furthermore, it would be valuable to separate (or "tag") the different gammas within individual events. This poster will present the efforts made in analyzing and tagging de-excitation and bremsstrahlung gammas in low-energy charged current neutrino interactions using Liquid Argon Software (LArSoft).

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## Low Radon Background Techniques For The SuperNEMO Experiment

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Abstract: SuperNEMO is a tracker-calorimeter neutrinoless double beta decay experiment using selenium-82,which has a designed capability to reach half-life sensitivity of T1/2 > 10ˆ26 years, equivalent to an effective Majorana neutrino mass of [U+3008]mββ[U+3009]< 40 - 100 meV. To achieve this sensitivity, SuperNEMO aims to be a zero background 0vbb experiment in the first phase Demonstrator Module . This target placed challenging demands on the radiopurity of detector components and the radon activity within the tracker. All internal detector components are screened for radon emanation to minimise radon levels. Measurements of the potential radon

contamination have allowed us to confirm that the tracker will meet our target radiopurity of 0.15mBq/m^3.

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## Constraints on Large Extra Dimensions from MINOS and MINOS+

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The MINOS experiment was designed to study neutrino oscillation between two steel-scintillator tracking calorimeters separated by a distance of 735 km using muon neutrinos and antineutrinos generated in the NuMI facility at Fermilab. Running for ten years with a neutrino beam peak energy of 3 GeV, MINOS yielded some of the best constraints on the atmospheric neutrino oscillation parameters to date. The MINOS+ experiment subsequently ran for about three years using a neutrino beam designed for the NOνA experiment, increasing the beam peak energy to 7 GeV. This shift to higher neutrino energies improves the sensitivity to exotic phenomena such as large extra dimensions. Assuming the existence of large extra dimensions, sterile neutrinos arise as Kaluza-Klein states. Mixing between the active neutrinos and Kaluza-Klein states alters the neutrino oscillation probabilities, allowing neutrino oscillation experiments to constrain the size of large extra dimensions. Using a MINOS era NuMI beam exposure of 10.6E20 protons-on-target, we combined muon neutrino charged current and neutral current data sets from the Near and Far Detector and observed no evidence for deviations from standard three-flavor neutrino oscillation. This result will be presented together with the status of the MINOS+ large extra dimensions search.

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## Latest results from the Borexino solar neutrino program

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The Borexino experiment, installed at Gran Sasso National Laboratory (LNGS) in Italy, is one of the main actors in the field of precision measurement of solar neutrinos. Thanks to the unprecedented radiopurity level achieved after an intensive purification campaign in 2010-2011, Borexino was able to collect valuable data that allowed to improve the accuracy of its previous results on solar neutrinos rate. In this contribution we present the first simultaneous measurement of the interaction rate of pp, pep and Be7 solar neutrinos, based on data collected from 2011 and 2016.
Among the analysis methods of this measurement, a new approach to a full multivariate analysis was adopted. Multivariate analysis is particularly helpful in enhancing the background discrimination in the fit -by exploiting the spatial distribution and pulse shape information- but can also improve the energy resolution by taking into account eventual variation in the detector response depending on the position inside the detector.

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## ProtoDUNE: from DAQ to CP Violation

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DUNE is a planned long-baseline neutrino experiment in the US. It consists of the world's most intense neutrino beam at Fermilab (Batavia, IL) and a 70 kT liquid argon detector complex at SURF (Lead, SD). The DUNE collaboration has a number of physics goals it aims to achieve by observing neutrino oscillations through 1300 km of matter, among which are the investigation of leptonic CP violation and the determination of the neutrino mass hierarchy.
The scale of the DUNE experiment necessitates the construction of prototype detectors. To that end, two 0.77 kT liquid argon TPC detectors are currently under construction, bearing the name of ProtoDUNE. CERN hosts these detectors at its Neutrino Platform site and will supply them with particles of known energy and nature in order to test the technical aspects of the detector and calibrate its detection and reconstruction systems.
A sophisticated data acquisition (DAQ) system is required to process the signals coming from the ProtoDUNE and DUNE detectors. Whereas most DAQ systems of big experiments are single-purpose, rigid in their operation and expensive to install and upgrade, the FELIX (Front-End Link eXchange) system provides an alternative. It readily connects to commercial off-the-shelf hardware and thereby reduces the costs of a full DAQ chain significantly. It is under development by the ATLAS collaboration and is being explored by the ProtoDUNE-SP experiment.
Although not directly performed by the FELIX system, compression of the signals that pass through it is vital to minimise the data infrastructure requirements and to maximise the fraction of data that can be kept. As a slightly arbitrary target, the compressed data is intended to be at least four times smaller than uncompressed signals. Preliminary tests have shown that this target can be met and surpassed: compression factors over 5 have already been achieved.

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## Design of the PROSPECT Experiment

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PROSPECT is a reactor antineutrino experiment with primary goals of making a precise measurement of the 235U reactor antineutrino spectrum and performing a search for sterile neutrinos. The detectors will be deployed at short baselines of ∼ 7-12m from the High Flux Isotope Reactor at Oak Ridge National Laboratory. In addition to being optimally located to search for oscillations arising from Δ m2∼1eV2 sterile neutrinos, the short distance of the detector from the reactor provides a large ν[U+23AF][U+23AF][U+23AF]e flux from the reactor core. However, the close proximity also poses challenges such as constraints on space, lack of overburden and backgrounds from the reactor. Therefore, the detector must be designed to have excellent background rejection capabilities, along with good position and energy resolution, to meet the physics goals of the experiment. PROSPECT's use of segmented 6Li-loaded liquid scintillator detector target enables the realization of these requirements. In this poster, we give a detailed description of the experimental strategy of PROSPECT, the PROSPECT detector design, and supporting R&D activities.

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## Calibrating Neutrino-Cube Detector for NIN Measurement at SNS

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The COHERENT experiment is currently taking data at the Spallation Neutron Source (SNS) aiming to detect the Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) for the first time. One of the least known but important backgrounds for this measurement is Neutrino-Induced Neutrons (NINs) produced in the shielding of the CEvNS detectors – another process that has

not been observed before. In order to measure this background, the COHERENT collaboration developed the Neutrino-Cube detectors that consist of four liquid-scintillator cells surrounded by the target material. The Lead and Iron Neutrino Cubes are installed and presently taking data at the SNS.
The four Neutrino-Cube liquid-scintillator cells were calibrated at the Triangle Universities Nuclear Laboratory (TUNL) in January of 2015 using radioactive sources and a neutron beam available there. The analysis of those calibration measurements is presented in this poster.

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## Improving Multi-Ring, Multi-GeV Event Reconstruction in Super Kamiokande

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This poster will summarize recent progress in improving Super-Kamiokande event reconstruction for multi-ring, multi-GeV events. Here I present methods to increase efficiency in the reconstruction of events where there are symmetric back-to-back multi-GeV e-like rings. Among other applications, applying these methods will lead to increased efficiency in detecting dinucleon decay in Super-Kamiokande.

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## The Ultra Low Background Laboratory at Idaho State University

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The Deep Underground Neutrino Experiment (DUNE) hopes to study in great detail atmospheric, solar and supernova neutrino events. In order to do so, the background radiation at both the near detector (at Fermilab) and the far detector (at the Sanford research facility in South Dakota) must be understood in great detail. The Low Background Laboratory (LBL) is to be built at Idaho State University (ISU) to understand this background radiation and will be used to control the radio-purity of materials used in the construction of both of the DUNE detectors. The goal of the proposed LBL is to provide a tool to identify the most practical and radiologically clean materials to be used by DUNE and to model the background radiation to be expected in the DUNE detectors over the next 20 years. The cosmic ray background at 4850 feet depth will be relatively small. The background from naturally occurring radioactive isotopes however, is expected to be substantial. Just one of the radioactive isotopes in the detector, i.e. 39Ar, is expected to produce a 20KHz background signal, which will severely degrade the detector performance at low energy. Other natural radioactive isotopes, e.g. 40K, 220Rn and 222Rn and the other isotopes from the Uranium and Thorium decay chains, are expected to produce comparable, or higher backgrounds. The LBL will allow us to substantially reduce those radiological backgrounds which we can control by allowing us to select construction materials not only for their performance, but also for their radiological purity. In order to measure as accurately as possible the radiological purity of construction materials, the LBL will reduce the Radon related background by an expected 90% by placing the entire detector system in a class 10000 clean room with autonomous HVAC system, HEPA filters, and the ability to maintain overpressure. The combination of passive and active shielding will substantially reduce the background. We will estimate the background reduction factor with Monte Carlo simulations and in situ measurements. Finally, the LBL will model the background radiation to be expected at both the near and far detectors using GEANT4 on the College of Science and Engineering's Minerve cluster.

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## Precision Measurement of the Reactor Antineutrino Spectrum with PROSPECT

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PROSPECT, the Precision Reactor Oscillation and Spectrum Experiment, is a short baseline reactor antineutrino experiment that aims to probe eV-scale sterile neutrinos and precisely measure the antineutrino spectrum generated from a Highly Enriched U-235 reactor. The PROSPECT antineutrino detector, a 4-ton movable optically segmented Li-6 loaded liquid scintillator detector will be deployed at the High Flux Isotope Reactor at Oak Ridge National Laboratory at baselines ranging within 7-12m. With an energy resolution of < 4.5% at 1 MeV and a daily interaction rate of about ˜700 antineutrinos/day, PROSPECT will make the highest precision measurement of an HEU reactor spectrum. In this poster, we describe PROSPECT's spectral measurement and its ability to shed light on the spectral discrepancies observed in the [U+1D703]-13 experiments.

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## Investigating the Reactor Antineutrino Anomaly with the Precision Reactor Oscillation and Spectrum Experiment (PROSPECT)

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Recent reactor neutrino experiments aimed for the study of neutrino oscillations exhibited anomalies in flux and the antineutrino spectrum called the Reactor Antineutrino Anomaly. Suggested explanations to the ˜6% deficiency of observed flux with respect to the theoretical predictions include both flaws in theoretical model of reactor antineutrino spectrum and existence of eV-scale sterile neutrino state leading to meter-scale neutrino oscillations. The Precision Reactor Oscillation and Spectrum Experiment (PROSPECT) was developed to study this anomaly by looking at antineutrino oscillations at short (<12 m) baselines from a highly-enriched (˜93% 235U) uranium reactor core. The antineutrino flux and spectrum will be precisely measured by a single movable detector at a range of baselines from the reactor core. The goals of the experiment include the search for eV-scale sterile neutrinos, testing reactor antineutrino model with antineutrino spectrum produced by a highly-enriched uranium core reactor, and obtaining new data complementary to the existing nuclear data measurements.

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## Neutron detection in the SoLid experiment

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The SoLid experiment aims to make a measurement of very short baseline neutrino oscillations using reactor anti-neutrinos. For this purpose, a highly segmented detector was build out of PVT cubes lined with a 6LiF:ZnS(Ag)layer.
Unlike neutrino experiments conducted deep underground, neutrino detectors used in a reactor environment need to operate in high levels of background radiation. Therefore, a reliable distinction between the neutrons produced in inverse beta decay events and signals caused by other background interaction is crucial.
This poster presents a unique neutron detection method and its performance: The composite of scintillation materials with different time constants enables the efficient use of pulse-shape analysis to discriminate against electromagnetic signals.

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## Towards a selection of NuMI nue events at MicroBooNE

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Measuring the nue CC cross section using the off-axis NuMI neutrinos will be crucial for reducing cross section systematics for current and future oscillation measurements at short and long baselines. However, as MicroBooNE is a surface detector cosmic rays interacting inside the liquid argon are the dominant source of background for this study. While numu and NC events are also backgrounds, these will be considered in future studies, building upon the work-in-progress selection using Pandora-based reconstruction.

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## A study of charged kaon-nucleon total interaction cross section in liquid argon.

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We present a study of the charged kaon-nucleus total interaction cross section in Liquid Argon (LAr) performed on LArIAT data. The kaon-nucleus total interaction cross section has never been measured in LAr and it is a fundamental input to proton decay studies in future Liquid Argon Time Projection Chamber (LArTPC) experiments such as DUNE. LArIAT, a small LArTPC deployed in a calibration test beam line at Fermilab, is the perfect venue to study kaons in a controlled environment. The LArIAT beam line detectors allow identification of kaons and measurement of their momentum before entering the TPC. The precise calorimetric energy reconstruction and excellent tracking resolution of the LArTPC technology enables the measurement of the total differential cross section for the tagged kaons.

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## Charged-current single neutral pion production and energy scale in MINERvA

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MINERvA is a neutrino scattering experiment that uses the NuMI beamline with the goal of measuring neutrino-nucleus cross sections on targets of different materials with high precision, as well as studying the internal structure of the nucleons of those materials. Among the different kinds of neutrino interactions that occur in the detector, charged and neutral pion production are significant since they represent a large fraction of the events that can be detected. In particular, the study of neutral pion production in multiple targets acquires relevance since not only it will provide constraints to the systematic errors of appearance and disappearance oscillation results in the range of energies of NOvA and DUNE, but also it will help to understand the underlying processes that occur inside of the nucleus in the form of final state interactions. Previous results on this topic using a "Low Energy" antineutrino beam of 3.6 GeV in plastic scintillator has been shown by MINERvA in the past few years. On this poster, I will present the current status of the single neutral pion production in C, Fe and Pb targets using a "Medium Energy" neutrino beam of 6 GeV, as well as the future steps in order to achieve the goal of a precise cross section measurement on these materials.

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## Studies of Proton Productions and Beam Target Scans to Improve BNB Flux Predictions at MicroBooNE

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The global neutrino physics program is currently focused on studying neutrino oscillations as they are a powerful probe to understand many important questions about the universe such as the matter-antimatter asymmetry. Oscillation measurements require a thorough understanding of neutrino beams and the interactions they induce in order to accurately reconstruct the incoming neutrino energy and estimate the initial neutrino flux. The neutrino beam flux uncertainties currently form the dominant systematics for both cross section and oscillation measurements of neutrinos. My research is a two-part approach to improving the Booster Neutrino Beam (BNB) flux prediction and related systematics for the MicroBooNE experiment at Fermilab: 1. Analyze BNB target scan data to accurately measure the delivery of protons on target (POT) along with optimizing the beam optics to minimize POT losses, and 2. Incorporate the long target and proton production data from the HARP experiment into the MicroBooNE BNB flux prediction and validate it. For the first approach a comparison of target scans attempting to identify the cause of unexpected asymmetry found in one scan is in progress. In the second approach, we have examined the contribution of secondary protons to the net neutrino flux by the current simulation to determine the potential effect of incorporating HARP proton production data. Current plans are to fit the HARP proton production data so that it can be extrapolated beyond the measured bounds and applied to the beam Monte-Carlo.

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## Measuring of Longitudinal Electron Diffusion in Liquid Argon

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Liquid Argon Time Projection Chambers (LArTPCs) are a rising technology in the field of experimental neutrino physics. LArTPCs use ionization electrons and scintillation light to reconstruct neutrino interactions with exceptional calorimetric and position resolution. Furthermore, understanding how ionization electrons diffuse as they traverse the detector can help to improve the timing resolution. In this poster, we outline a Monte Carlo method to extract the diffusion constant based on the signal pulse spread in time of the ionization electrons. This analysis is highly sensitive to low-level effects (electronics noise, detector response, ADC rounding, etc.), so we use a sample with physics effects turned off in order to first correct for these low-level effects. Looking forward, we plan to incrementally turn on physics effects in Monte Carlo, with the intention of applying this analysis to data once the Monte Carlo method is solidified.

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## NOvA Short-Baseline Tau Neutrino Appearance Search

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Standard three-flavor neutrino oscillations have well studied by a wide range of neutrino experiments. However, the anomalous results, such as electron-antineutrino excess seen by LSND and MiniBooNE do not fit the three-flavor paradigm. This can be explained by an additional fourth flavor sterile neutrino at a larger scale than the existing three flavor neutrinos. NOvA has two finely segmented liquid scintillator detectors operating 14.6 mad off-axis from the NuMI beam axis. The Near Detector is well suited for searching for anomalous short-baseline oscillations. This poster will present a novel method for selecting the oscillated tau-neutrino interactions with high purity at the Near Detector using a convolutional neural network(CNN). Using this method, the sensitivity to anomalous short-baseline tau-neutrino appearance due to sterile neutrino oscillations will be presented.

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## Progress of an Alternative Measurement of the Inclusive Muon Neutrino Charged-current Cross Section in the NOvA Near Detector

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NOvA is a long-baseline neutrino oscillation experiment. It uses the NuMI beam from Fermilab and two sampling calorimeter detectors off-axis from the beam. The 293 ton Near Detector measures the unoscillated neutrino energy spectrum, which can be used to predict the neutrino energy spectrum at the 14 kton Far Detector at Ash River, MN. The Near Detector also provides an excellent opportunity to measure cross sections with high statistics, which benefit current and future long-baseline neutrino oscillation experiments. This analysis implements new algorithms to identify $\nu_\mu$ charge-current events by using visual deep learning tools such as convolutional neural networks. In this talk we present the status of a measurement of the inclusive $\nu_\mu$ CC cross section in the NOvA Near Detector.

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## Sterile neutrino search in the NOvA Far Detector

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The three-flavor neutrino model is supported by the results from the majority of neutrino oscillation experiments. The anomalous results from short-baseline experiments, such as LSND and MiniBooNE, can be explained using the sterile neutrino hypothesis. The search for sterile neutrino in NOvA can be done by measuring the depletion of Neutral Current events at the Far Detector with respect to the Near Detector prediction. In this poster I will demonstrate NOvA's ability to look for sterile neutrinos, and will discuss the improvements being readied for future analyses. These improvements include a shape fit of the Far Detector energy spectrum, enabled by improved modelling of the detector response and of neutrino interactions, and a joint fit of the Far and Near detectors, extending the range of sterile mass-squared splitting NOvA can probe to larger values.

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## Exploring nucleon spin structure in MicroBooNE

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The net contribution of the strange quark spins to the proton spin, $\Delta s$, can be determined from neutral current elastic neutrino-proton interactions at low momentum transfer combined with data from electron-proton scattering. This is because the probability of neutrino-proton interactions depends on the axial form factor, which represents the spin structure of the proton and can be separated into its quark flavor contributions. Low momentum transfer neutrino neutral current interactions can be measured in MicroBooNE, a high-resolution liquid argon time projection chamber (LArTPC) in its first year of running in the Booster Neutrino Beamline at Fermilab. The signal for these interactions in MicroBooNE is a single short proton track. We present our work on the automated reconstruction and classification of proton tracks in LArTPCs, an important step in the determination of neutrino-nucleon cross sections and the measurement of $\Delta s$.

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## Optimization of neutrino flux with the new NOvA target design

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NOvA (NuMI Off-axis νe Appearance) is a long baseline neutrino oscillation experiment designed to search for both νe appearance and νμ disappearance. Fermilab NuMI (Neutrinos at Main Injector) facility produces an intense beam of neutrinos (narrow band νμ beam peaked at 2 GeV in energy) using a high intensity 120 GeV proton beam. The NuMI target is designed to maximize the neutrino yield. The relative position of two horns and the target optimizes the momentum focus for pions and hence the neutrino beam energy. We compared the neutrino flux in the NOvA Near and Far detector with different target designs and different Horn2 configuration. Here, we present the New Target design which gives about 17% (20%) more neutrino (anti-neutrino) yield as compared to the event yield with the existing NuMI target.

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## Quasielastic production of polarized hyperons induced by antineutrino and electron

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Recently, the availability of high intensity beams of anti-muon neutrino and electron at the accelerator allowed us to study the weak quasielastic production of single hyperon($\Lambda/\Sigma$) off the nucleon. Although the production of the hyperons is Cabibbo suppressed as compared to the $\Delta$ production, it may be comparable to the $\Delta$ production in the region of low electron energies due to the threshold effects. We shall discuss the differential scattering cross section for the production of single hyperon and present the alternative method of determination of the axial dipole mass M_A, electric neutron form factor G^n_E(Q^2), pseudoscalar form factor etc. by studying the longitudinal and perpendicular components of the polarization of the produced hyperon.

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## Beam-Plasma Interaction in Muon Ionization Cooling Lattices

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New computational tools are essential for accurate modelling and simulation of the next generation of muon-based accelerators. One of the crucial physics processes specific to muon accelerators that has not yet been simulated in detail is beam-induced plasma effect in liquid, solid, and gaseous absorbers. We report here on the progress of developing the required simulation tools and applying them to study the properties of plasma and its effects on the beam in muon ionization cooling channels.

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## Characterisation of the Ce-144 source for the SOX experiment.

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Existence of a light sterile neutrino would have important consequences on astrophysics and cosmology. SOX is the only experiment aiming at testing this hypothesis using a punctual radioactive source. A 3-5 PBq Ce-144 source is actually under production and will be positioned under Borexino in 2018. Precise knowledge of the source is one of the main challenge of this experiment, based on rate and shape neutrino measurement. Two critical parameters are the heat released by the source for activity measurement and the expected neutrino spectrum in the detector. We first describe the SOX experiment insisting on Ce-144 source production. Then, we focus on Saclay installations dedicated to constrain radioactive contamination inside the source using representative samples. Alpha, gamma and mass spectroscopy calibration and simulation are discussed and competitive constrains are derived. Finally, a status on Ce-144/Pr-144 beta shape measurements is done as well as presentation of future measurement.

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## Cosmic Removal at MicroBooNE

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MicroBooNE is a liquid-argon-based neutrino experiment, which began collecting data in Fermilab's Booster neutrino beam in October 2015. Physics goals of the experiment include probing the source of the anomalous excess of electron-like events in MiniBooNE, while also measuring low-energy neutrino cross sections and providing important R&D for future detectors. The MicroBooNE detector is on the surface and is subject to a constant exposure of cosmic rays. They are a major source of background as neutrino interactions happen once every thousands of recorded events, and are overlapped with 20-30 comics rays. This poster shows techniques that can be used to remove cosmic rays that will benefit every MicroBooNE analyses.

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## MiniTimeCube

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The MiniTimeCube (mTC) aims to be a small compact portable antineutrino detector with directional capabilities.

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## Muon neutrino disappearance measurement at MINOS+

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The MINOS experiment ran from 2003 until 2012 and produced some of the best measurements of the atmospheric neutrino oscillation parameters $\Delta m^2_{32}$ and $\theta_{23}$ using muon neutrino disappearance of beam and atmospheric neutrinos and electron neutrino appearance of beam neutrinos. The MINOS+ experiment succeeded MINOS in September 2013. For almost three years MINOS+ has been collecting data from the Medium Energy NuMI neutrino beam at Fermilab. Results of the muon neutrino disappearance analysis from the first two years of MINOS+ data will be presented. These results will be compared to and combined with the MINOS measurement.

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## Flashmatching for the Pandora-based 2 electron neutrino selection in 3 MicroBooNE

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MircoBooNE is the first liquid argon time projection chamber in an extensive short-baseline neutrino oscillation programme using the booster neutrino beam at Fermilab. Its principal physics topic is to clarify the excess of low-energy electron-like events that were seen by its predecessor, MiniBooNE. This poster describes the first efforts towards using optical information to mitigate the background in the Pandora based low-energy excess analysis. Special emphasis is put on matching information recorded by the light system to information from the time projection chamber, and its importance for the electron neutrino selection.