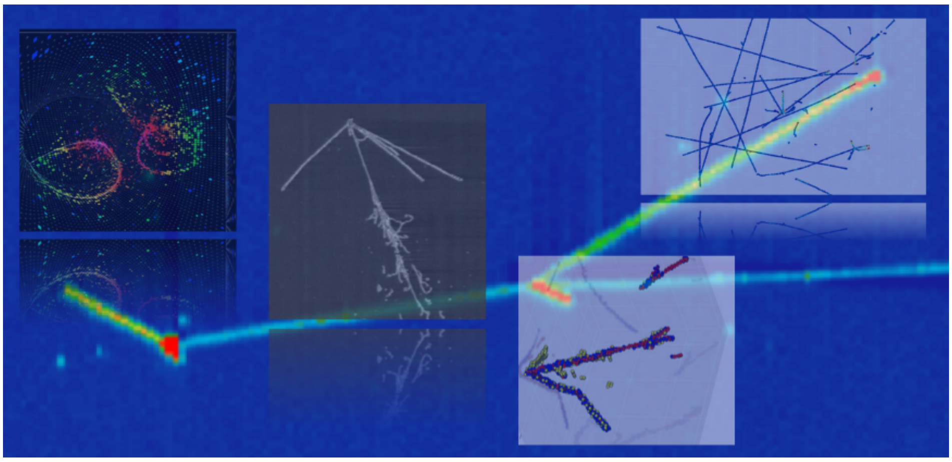
Neutrino Physics and Machine Learning 2023



Report of Contributions

https://indico.slac.stanford.edu/e/npml2023

Contribution ID: **1** Type: **Individual Talk**

Deep learning in voxelised neutrino detectors

Tuesday, 22 August 2023 09:15 (35 minutes)

Deep learning methods are becoming key in the data analysis of particle physics experiments. One clear example is the improvement of neutrino detection using neural networks. Current neutrino experiments are leveraging these techniques, which, in combination, have exhibited to outperform standard tools in several domains, such as identifying neutrino interactions or reconstructing the kinematics of single particles. In this talk, I will show various deep-learning algorithms used in the context of voxelised neutrino detectors. I will present how to design and use advanced deep-learning techniques for tasks such as fitting particle trajectories and understanding the particles involved in the vertex activity. All these methods report promising results and are crucial for improving the reconstruction of the interacting particle kinematics and enhancing the sensitivity to future physics measurements.

Primary author: Dr ALONSO MONSALVE, Saul (ETH Zurich)

Presenter: Dr ALONSO MONSALVE, Saul (ETH Zurich)

Session Classification: Session 1

Contribution ID: **2** Type: **Individual Talk**

Diffusion-Based Generative Modeling for LArTPC Images

Wednesday, 23 August 2023 16:25 (25 minutes)

Seeking to harness the power of generative modeling for neutrino physics, we have successfully generated high-fidelity images of track and shower particle event types. We implemented a diffusion model on the PILArNet public dataset comprising 2D images from a simulated Liquid Argon Time Projection Chamber (LArTPC). In this presentation, I will outline the methodology behind the score-based generative model developed by Song & Ermon in 2019, and measure the quality of our generated LArTPC images.

Primary authors: IMANI, Zeviel (Tufts University); WONGJIRAD, Taritree (Tufts University)

Presenter: IMANI, Zeviel (Tufts University)

Session Classification: Session 4

Contribution ID: **3** Type: **Collaboration Talk**

Applying Machine Learning to vertex recognition for neutrino interactions

The MINERvA experiment studies neutrinos cross sections with different nuclei. Neutrino vertex recognition plays a key role in reconstructing neutrino interactions. This research aims to enhance previous Machine Learning neutrino vertex recognition models produced in MINERvA using Deep Convolutional Neural Networks (DCNN). The approach focuses on extending neutrino interaction image information used as input to generate the models. The extension allows the DCNN to look for neutrino interactions in new regions not studied before. A Domain Adversarial Neural Network
(DANN) was also implemented to penalize differences between simulated data images and real data
images. The model performance is evaluated using recall, precision, and the harmonical mean F1 score, a traditional well-known metric used in this field. The F1 score considers both precision and recall, providing a comprehensive assessment of the model's performance. An extra label to recognize background activity was also implemented. The new models generated are the next version to use for the MINERvA experiment, it enables analysis of all events in the detector including the calorimeters enabling new high statistics analysis in MINERvA.

Primary author: Mr MORENO PALACIOS, Oscar (William & Mary)

Presenter: Mr MORENO PALACIOS, Oscar (William & Mary)

Session Classification: Session 1

Contribution ID: **4** Type: **Individual Talk**

Convolution Transformers for NOvA Event and Particle Classification

Wednesday, 23 August 2023 11:00 (25 minutes)

NOvA is a long-baseline neutrino experiment studying neutrino oscillations with Fermilab's NuMI beam. The experiment consists of two functionally identical detectors formed from plastic extrusions filled with a liquid scintillator for the purpose of observing the disappearance of muon neutrinos and the appearance of electron neutrinos. NOvA's recent oscillation measurements used convolution networks to determine neutrino flavor and reject backgrounds in both the near and far detectors. We introduce a transformer-based architecture known as TransformerCVN which accepts as input all event data as pixel map images and classifies both individual particles as well as the overall event interaction types in an end-to-end manner. By exploiting attention mechanisms, TransformerCVN is able to extract contextual information shared between all particles present in an event to improve reconstruction for both tasks. Additionally, the shared attention mechanisms allows us to produce interpretable attention maps, providing insight into specific particles and pixels of each particle's pixel map which are responsible for produced classification.

Primary authors: YANKELEVICH, Alejandro (University of California, Irvine); SHMAKOV, Alexander (University of California, Irvine)

Presenter: YANKELEVICH, Alejandro (University of California, Irvine)

Session Classification: Session 3

Contribution ID: **5** Type: **Individual Talk**

ML-Based Surrogate Modeling of Radiofrequency Quadrupole Accelerators

Wednesday, 23 August 2023 17:00 (35 minutes)

IsoDAR (Isotope Decay-At-Rest) is a state-of-the-art electron antineutrino source currently under development. Chief among the technical innovations that allow IsoDAR to reach an unprecedented 10 mA of 60 MeV protons is the inclusion of a radiofrequency quadrupole; a linear accelerator that pre-bunches and focuses the beam before injection into IsoDAR's cyclotron. IsoDAR's exceptionally high beam current means that nonlinear space charge effects balloon the computational runtime of high-fidelity simulations necessary for the RFQ's development. In this contribution, we present our efforts to build surrogate models, based on neural networks, that can (with <6% error on all relevant objectives) approximate beam characteristics for an RFQ of arbitrary design. These surrogate models are fast-executing, and have the potential to transform the way in which accelerator physicists engineer these and similar devices, by allowing users to quickly optimize accelerator design, to quantify uncertainty, and to tool real-time fine-tuning and commissioning softwares. While I present ML-enabled surrogate models'application to accelerator design, these techniques can easily be extended to detector engineering.

Primary author: VILLARREAL, Joshua (Massachusetts Institute of Technology)

Presenter: VILLARREAL, Joshua (Massachusetts Institute of Technology)

Session Classification: Session 4

Contribution ID: **6** Type: **Individual Talk**

Connecting the Dots: Using Multidetector Inputs in Machine Learning

Wednesday, 23 August 2023 14:20 (25 minutes)

The DUNE experiment expects to make some of the most precise measurements of neutrino oscillation parameters by using a neutrino beam originating at Fermilab and measuring it at the Sanford Underground Research Facility (SURF). To accomplish this, novel techniques are being used in both the near- and far-detector designs. Notably, the Liquid Argon Time Projection Chamber (LArTPC) near-detector uses a unique modularized design. A subset of the design, a prototype 2x2 module, is undergoing testing at Fermilab and expects to take data this year using the same beamline that the full DUNE experiment will use. In addition, the MINERvA detector has been repurposed to be used both upstream and downstream of the prototype 2x2. This work outlines efforts that have been made to utilize input from both the 2x2 prototype and MINERvA detectors to accomplish machine learning identification of the particle interactions.

Primary author: MICALLEF, Jessie (IAIFI at MIT and Tufts)

Presenter: MICALLEF, Jessie (IAIFI at MIT and Tufts)

Session Classification: Session 4

Contribution ID: **7** Type: **Individual Talk**

Accelerating event reconstruction in neutrino telescopes using sparse convolutional neural networks

Tuesday, 22 August 2023 10:55 (25 minutes)

Convolutional neural networks (CNNs) have seen extensive applications in scientific data analysis, including in neutrino telescopes. However, the data from these experiments present numerous challenges to CNNs, such as non-regular geometry, sparsity, and high dimensionality. In this talk, I will present sparse submanifold convolutions (SSCNNs) as a solution to these issues and show that the SSCNN event reconstruction performance is comparable to or better than traditional and machine learning algorithms. I will also discuss our current efforts to implement this type of network into the IceCube Neutrino Observatory.

Primary author: YU, Felix (Harvard University)

Presenter: YU, Felix (Harvard University)

Session Classification: Session 1

Contribution ID: **8** Type: **Individual Talk**

Faithful Pulse Shape Analysis for Germanium Detectors using Feature Importance Supervision

Friday, 25 August 2023 10:35 (25 minutes)

Experiments using the 76Ge isotope have set leading limits in the search for neutrinoless double beta decay, offering insights into the nature of neutrinos and the universe. The LEGEND experiment employs High Purity Germanium (HPGe) detectors for this purpose and dramatically reduces backgrounds using Pulse Shape Analysis (PSA). To enhance the analysis, we propose the implementation of a Neural Network with Feature Importance Supervision (FIS) for PSA in HPGe detectors. This machine learning model utilizes human knowledge of waveform features to accurately identify relevant elements of the signal and disregard noise. It exhibits promising results in distinguishing between multi-site gamma background events and the single-site signals associated with neutrinoless double beta decay events. By incorporating prior knowledge, the model achieves the aim of being "Right for the Right Reason" and overcomes the energy dependence of the more basic Neural Network classifier, introduced by the limitations of the training dataset available.

Primary author: KILGUS, Katharina (Universität Tübingen)

Co-author: LI, Aobo (Boston University)

Presenter: KILGUS, Katharina (Universität Tübingen)

Session Classification: Session 7

Contribution ID: **9** Type: **Collaboration Talk**

Machine Learning Applications for the neutrinoless double-beta decay search with LEGEND

Friday, 25 August 2023 09:35 (35 minutes)

The Large Enriched Germanium Experiment for Neutrinoless double-beta Decay (LEGEND) project searches for the lepton-number-violating neutrinoless double-beta (0vbb) decay of Ge-76. By utilizing High Purity Germanium (HPGe) detectors enriched with Ge-76 and immersing them directly into liquid argon (LAr), LEGEND combines the superior energy resolution of germanium detectors with the scintillating properties of LAr to significantly enhanced background reduction.

The recent advancements in computation have paved the way for machine learning to emerge as a powerful tool in various aspects of analysis and simulation within the LEGEND project. A wide range of machine learning techniques is being explored, including unsupervised data cleaning networks for real-time operation, pulse shape classification (Network Pulse Shape Analysis and Feature Importance Supervision), waveform reconstruction and spectrum fitting (Interpretable Boosted Decision Tree and RNN Dead Layer Fitting), Monte Carlo simulation and tuning (GAN waveform simulation and Cyclic Positional U-Net), and experimental design optimization (Multi-Fidelity Gaussian Process). In this talk, I will introduce these novel approaches which hold great promise for increasing the 0vbb half-life sensitivity, benefiting not only the LEGEND project but also other fundamental physics experiments like 0vbb searches.

Primary author: SCHUETZ, Ann-Kathrin (Lawrence Berkeley National Laboratory)

Presenter: SCHUETZ, Ann-Kathrin (Lawrence Berkeley National Laboratory)

Session Classification: Session 7

Contribution ID: **10** Type: **Individual Talk**

Translating Near to Far Detector with Deep Learning for DUNE-PRISM

Wednesday, 23 August 2023 15:05 (25 minutes)

The Deep Underground Neutrino Experiment (DUNE) is a next-generation long-baseline neutrino oscillation experiment that aims to measure CP-violation in the neutrino sector as part of a wider physics programme. DUNE consists of a near and far detector in a high power wide band neutrino beam. The Precision Reaction Independent Spectrum Measurement (PRISM) refers to the capacity of part of the DUNE near detector to move off-axis from the beam to sample different neutrino energy spectra. Due to the wide range of off-axis positions, the set of fluxes can be treated as a linearly independent basis and combined to approximate any target flux. This is used to extract oscillation parameters with little dependence on an interaction model by producing a prediction of the oscillated spectrum at the far detector using near detector measurements. An important part of this extrapolation is to correct for the differences in resolution and efficiency of the detectors with minimal reliance on Monte Carlo. This work presents a deep learning approach to accomplish this by predicting the far detector response given a near detector neutrino event. The problem is posed as an image-to-image translation between two domains defined by the distinct types of detector technology. The capacity for the model to accurately predict far detector reconstructed variables is demonstrated and the network is integrated in the simulation chain to conduct an initial study of its performance over Monte Carlo based smearing.

Primary author: WILKINSON, Alex (University College London)

Presenter: WILKINSON, Alex (University College London)

Session Classification: Session 4

Contribution ID: **11** Type: **Collaboration Talk**

nEXO's Machine Learning: Signal Analysis for Neutrinoless Double Beta Decay (remote)

Thursday, 24 August 2023 09:00 (35 minutes)

The nEXO Experiment is a search for neutrinoless double beta decay in 136Xe using a 5-ton liquid xenon time projection chamber. This talk introduces the science and design of nEXO and presents an overview of role machine learning plays in its analysis.
nEXO's machine learning development currently focuses on the analysis of direct-from-sensor signals. nEXO employs an array of electrodes to sense drift charge, and these electrodes produce high-dimensional data. This dataset is a challenging target for conventional analysis, but it is very amenable to machine learning. Machine learning assists with the analysis of signal correlations across multiple channels and times while minimizing the impact of sensor noise.
nEXO employs a neural network discriminator to identify gamma ray backgrounds, which are distinguished from double beta decays due to their high prevalence of multiple interaction sites. In addition to superior performance, machine learning allows nEXO to quickly adapt this discriminator algorithm to evaluate different detector designs.
In addition to the discriminator, nEXO is developing a machine learning denoiser capable of enhancing energy resolution by removing sensor noise from signals. This denoiser can be trained unsupervised without any ground truth noiseless signals. This talk will present preliminary concepts for this denoiser.

LLNL-ABS-851495
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Primary author: BRODSKY, Jason (LLNL)

Presenter: BRODSKY, Jason (LLNL)

Session Classification: Session 5

Contribution ID: **12** Type: **Individual Talk**

An Introduction to Quantum Machine Learning for Neutrino Astronomy

Thursday, 24 August 2023 13:00 (35 minutes)

Next-generation experiments in particle physics necessitate immense computational resources. Quantum Machine Learning (QML) could be a potential solution to mitigate these computational challenges. This talk will illuminate recent advances in QML and discuss our efforts to introduce this budding technology to IceCube. I will detail our methodology for translating classical data into quantum states and elaborate on our strategy for classifying IceCube neutrino events using a Variational Quantum Classifier (VQC). VQCs exploits the mapping of input data to an exponentially large quantum state space to enhance the ability to find an optimal solution. Our aim is to initiate a paradigm shift from a classical landscape to a hybrid or even possibly a fully quantum data analysis protocol.

Primary authors: Mr ZHELNIN, Pavel (Harvard University); Prof. ARGÜELLES-DELGADO, Carlos (Harvard University); Mr LAZAR, Jeff (Harvard University)

Presenters: Mr ZHELNIN, Pavel (Harvard University); Prof. ARGÜELLES-DELGADO, Carlos (Harvard University); Mr LAZAR, Jeff (Harvard University)

Session Classification: Session 6

Contribution ID: **13** Type: **Individual Talk**

Implicit Neural Representation as a Differentiable Surrogate for Photon Propagation in a Monolithic Neutrino Detector

Wednesday, 23 August 2023 13:45 (25 minutes)

Modern neutrino experiments employ hundreds to tens of thousands of photon detectors to detect scintillation photons produced from the energy deposition of charged particles. A traditional approach of modeling individual photon propagation as a look-up table requires high computational resources, and therefore it is not scalable for future experiments with multi-kiloton target volume.

We propose a new approach using SIREN, an implicit neural representation with periodic activation functions, to model the look-up table as a 3D scene. It reproduces the acceptance map with high accuracy using orders of magnitude less number of parameters than the look-up table. As a continuous and differentiable parameterization, SIREN also represents a smooth gradient surface. As such, it allows downstream applications such as inverse problem-solving and gradient-based optimizations. We demonstrate a data-driven method to optimize the SIREN model and an application of reconstruction using data collected from the Deep Underground Neutrino Experiment's (DUNE) near detector prototype.

Primary author: TSANG, Patrick (SLAC)

Presenter: TSANG, Patrick (SLAC)

Session Classification: Session 4

Contribution ID: **14** Type: **Individual Talk**

NuDot and Machine Learning

(Submitted as a poster request)
NuDot is a monolithic ton-scale liquid scintillator research and development testbed. Presently, NuDot aims to reduce one of the dominant backgrounds in modern and future neutrinoless double beta decay ($0\nu\beta\beta$) searches: the solar neutrino background. It will demonstrate the ability to separate the Cherenkov emission by MeV electrons from the scintillation radiation, through fast timing resolution and high speed electronics. The separation of Cherenkov radiation can be further used to distinguish the single electron emission by solar neutrinos from the back-to-back emission in $0\nu\beta\beta$. This separation is done using low time transit spread photomultiplier tubes. This poster will explain the NuDot project and how new methods in machine learning can be used to improve signal extraction.

Primary author: SARFRAZ, Masooma

Presenter: SARFRAZ, Masooma

Session Classification: Session 7

Contribution ID: **15** Type: **Collaboration Talk**

Design, implementation and reliability of machine learning algorithms in JUNO

Thursday, 24 August 2023 13:45 (35 minutes)

The Jiangmen Underground Neutrino Observatory (JUNO) is a neutrino experiment currently under construction in China. Its main goals are the mass ordering measurement expected to be determined with a 3σ confidence level in 6 years and the precise measurement of the oscillations parameters θ_{12}, Δm^2_{21} and Δm^2_{31} (Δm^2_{32}) at the per-mil level. To achieve such precision, JUNO need to reach an energy resolution of 3\% at 1 MeV and the best spatial resolution possible for event selection. Alongside the traditional methods such as likelihood maximisation, we are also exploring the usage of machine learning to improve our precision and ensure a robust and coherent reconstruction by having multiple independents algorithms. In this talk, I will discuss and present the different architectures of Neural Networks and Boosted Decision Tree that have been designed to reconstruct neutrino events and discuss their implementation and their reliability.

Primary author: IMBERT, Leonard (Subatech, Nantes, France)

Presenter: IMBERT, Leonard (Subatech, Nantes, France)

Session Classification: Session 6

Contribution ID: **16** Type: **Individual Talk**

HITMAN: Machine Learning Likelihoods for Arbitrary Optical Neutrino Detectors

Thursday, 24 August 2023 16:20 (35 minutes)

In this talk, we present Highly Parallel Inference Technique for Monitoring Anti-Neutrinos (HITMAN), an inference tool that combines the extended maximum likelihood decomposition (EML) with neural ratio estimators (NREs) to produce likelihood functions for optical neutrino detectors of arbitrary geometry and material properties. By employing the EML, HITMAN reduces the input dimension of the likelihood, enabling the use of lightweight, densely connected networks to generate NREs. This approach eliminates the need to modify the network structure for different neutrino detectors, enabling rapid-turnaround detector design studies by removing the need for labor-intensive manual creation of likelihood functions. Additionally, the EML method minimizes the amount of training data necessary for network training, reducing the computational resources required by simulation. Our project embodies the principle: 'If you can simulate it, you can reconstruct it.' We demonstrate the effectiveness of HITMAN by applying this technique to two specific neutrino detectors. The first is Eos, a ton-scale antineutrino detector using water-based liquid scintillator as the target medium. The second is LiquidO, an optical particle detector with opaque scintillator enabling high-precision event reconstruction.

Primary authors: WENDEL, Garrett (Penn State University); Prof. COWEN, Douglas (Penn State)

Presenters: WENDEL, Garrett (Penn State University); Prof. COWEN, Douglas (Penn State)

Session Classification: Session 6

Contribution ID: **17** Type: **Individual Talk**

Uncertainty Quantification for DUNE ND Reconstruction

Wednesday, 23 August 2023 15:40 (25 minutes)

As the role of machine learning methods in neutrino science expands, it is more and more important to have a reliable estimate of the uncertainty of the predictions of such models. Traditional uncertainty propagation does not capture the aleatoric and epistemic uncertainties intrinsic to these models and cannot characterize the models' robustness to out-of-distribution inputs. This talk describes a two-model system in which an upstream probabilistic neural network (PNN) will estimate the energy deposition of simulated events in the DUNE ND-LAr detector. Downstream reconstruction models will be trained with and without the uncertainty information provided by the upstream model in order to demonstrate the impact of uncertainty quantification.

Primary author: DOUGLAS, Dan (SLAC)

Presenter: DOUGLAS, Dan (SLAC)

Session Classification: Session 4

Contribution ID: **18** Type: **Individual Talk**

Particle Trajectory Reconstruction and Euclidian Equivariant Neural Networks

Tuesday, 22 August 2023 14:45 (25 minutes)

Training neural networks to operate on three-dimensional trajectories from particle detectors is challenging due to the large combinatorial complexity of the data in three dimensions. Using networks that incorporate Euclidian Equivariance could prove to be very beneficial in reducing the need for data augmentation. Our focus is on data from neutrino experiments using liquid argon time projection chambers.

Primary author: ALTERKAIT, Omar (Tufts University)

Presenter: ALTERKAIT, Omar (Tufts University)

Session Classification: Session 2

Contribution ID: **19** Type: **Individual Talk**

Pointlike events discrimination in the RED-100 experiment using ML algorithms (remote)

Thursday, 24 August 2023 15:30 (25 minutes)

RED-100 is a xenon two phase emission detector designed to study coherent elastic neutrino nucleus scattering (CEvNS). In 2021-22 it was deployed at Kalinin NPP (Udomlya, Russia) 19 meters from the reactor core. More information about CEvNS and the RED-100 experiment is presented in the talk "The RED-100 experiment"(Dmitry Rudik) while this talk is about reducing specific background component. This type of background comes from spontaneous emission of single electron events (SE) at significant rate. Signal from coincidence of several SE can mimic rare CEvNS event. Hence complex discrimination algorithms are required. Spatial distribution of signals in channels in these two cases is different and can be used for selection. We carried out a detailed simulation of the SE signals and developed two algorithms based on neural networks in order to solve this problem. Results of simulation and neural networks are shown and discussed.

Primary author: RAZUVAEVA, Olga

Presenter: RAZUVAEVA, Olga

Session Classification: Session 6

Contribution ID: **20** Type: **Collaboration Talk**

The RED-100 experiment (remote)

Thursday, 24 August 2023 14:45 (35 minutes)

Coherent elastic neutrino nucleus scattering (CEvNS) off atomic nuclei, predicted over 45 years ago, was recently observed in 2017 within the COHERENT experiment. With its cross section depending quadratically on the number of neutrons in nuclei, CEvNS surpasses all other known neutrino interaction cross sections for heavy elements. This unique characteristic makes it ideal for monitoring reactors using compact neutrino detectors.

This talk focuses on RED-100, a two-phase LXe neutrino detector designed to detect and study CEvNS in close proximity to the reactor core. Deployed at the Kalinin nuclear power plant in 2021, RED-100 successfully collected data during both reactor-off and reactor-on periods. However, the region of interest (ROI) is plagued by a significant background of coincidental single electrons caused by high energy depositions in the LXe bulk. This background cannot be eliminated by conventional cuts, necessitating the development of specialized machine learning and deep learning approaches for mitigation.

In this talk an overview of the experiment is provided, sources of background are discussed, with a particular emphasis on the primary background in the ROI. Furthermore, the presentation outlines plans for the future upgrade of the detector to enhance its performance.

Primary author: RUDIK, Dmitrii (MEPhI)

Presenter: RUDIK, Dmitrii (MEPhI)

Session Classification: Session 6

Contribution ID: **21** Type: **Collaboration Talk**

Nova collaboration talk

Wednesday, 23 August 2023 10:00 (35 minutes)

NOvA is a leading long-baseline neutrino experiment. Using neutrinos from the ~900 kW NuMI beam at Fermi National Accelerator Laboratory, with a near detector on site and an 810 km baseline to the far detector, in Ash River, Minnesota, NOvA can probe neutrino oscillations. Both detectors are functionally similar fine-grained segmented calorimeters, which makes the readout well-suited as an input for computer vision algorithms. NOvA has employed machine learning in several analyses, including our most recent 3-flavor oscillation results. These algorithms identify topological features and use them to predict neutrino interaction flavor and particle identification. For our most recent 3-flavor oscillation analysis, we used a new optimized architecture and improved training that both enhanced performance for physics analyses and made the network more robust against systematic uncertainties. We also introduced a new network designed to filter out cosmic interactions as early as possible in our reconstruction chain. Work is underway to develop our next generation of interaction flavor and particle identification algorithms, in addition to new machine learning networks for reconstruction tasks, such as vertex finding, that have used traditional techniques until now.

Presenter: BACK, Ashley (Indiana University)

Session Classification: Session 3

Contribution ID: **22** Type: **Collaboration Talk**

Search for solar neutrino and light dark matter with the PandaX-4T experiment

Thursday, 24 August 2023 10:35 (35 minutes)

The PandaX-4T experiment aims to search for potential dark matter interactions. With significant technical improvements, PandaX-4T achieves unprecedented sensitivity at the low-energy edge of LXe detectors, opening a new window for observing solar neutrinos. Using commissioning data, two hybrid analyses are carried out to search for dark matter interactions, yielding world-leading results for neutrino-nucleus coherent elastic scattering from solar B8 neutrino, as well as for dark matter interactions with nucleons and electrons. These results demonstrate PandaX-4T's unique capability to search for low-energy interactions from solar and galactic sources.

Primary author: MA, Wenbo

Presenter: MA, Wenbo

Session Classification: Session 5

Contribution ID: **23** Type: **Collaboration Talk**

Machine Learning in KamLAND-Zen: An Old Detector Learning New ML Tricks

Friday, 25 August 2023 11:10 (35 minutes)

The KamLAND-Zen experiment is a multi-purpose neutrino detector in central Japan, with a broad neutrino science program. KLZ has produced world-leading results in the study of solar, geo, and astophysical neutrinos. Recently, KLZ has also set the world-leading limit on the majorana neutrino mass, the first such limit in the Inverted Mass Ordering region. Machine learning plays a key role in these analyses. ML models learn features that reject backgrounds by physical processes and/or particle species. We use ML to build likelihood models that connect backgrounds to the cosmic muons they originated from. ML also allows us to calibrate the KamLAND detector in real-time with the use of deployed calibration sources. By applying ML in these and more ways, we can use KamLAND to its' full scientific potential.

Primary author: SONG, Hasung (Boston University)

Presenter: SONG, Hasung (Boston University)

Session Classification: Session 7

Contribution ID: **24** Type: **Individual Talk**

Identifying Particles and Neutrino Final States with Convolutional Neural Networks in MicroBooNE

Tuesday, 22 August 2023 15:30 (35 minutes)

MicroBooNE, a Liquid Argon Time Projection Chamber (LArTPC) located in the ν_μ-dominated Booster Neutrino Beam at Fermilab, has been studying ν_e charged-current (CC) interaction rates to shed light on the measured MiniBooNE low energy excess. The LArTPC technology pioneered by MicroBooNE provides the capability to image neutrino interactions with mm-scale precision. Computer vision techniques can be used to process these images and aid in selecting ν_e-CC and other rare signals from large cosmic and neutrino backgrounds. We present a new suite of deep learning tools to reconstruct neutrino interactions in MicroBooNE, with a focus on a convolutional neural network used to accurately assign labels to reconstructed particles. We will show that these techniques can be used to select ν_e-CC events at purities and efficiencies that are competitive with the tools currently in use in MicroBooNE and that they have the potential to improve the sensitivity of future analyses.

Primary author: ROSENBERG, Matthew (Tufts University)

Presenter: ROSENBERG, Matthew (Tufts University)

Session Classification: Session 2

Contribution ID: **25** Type: **Individual Talk**

Differentiable simulation of the DUNE near detector liquid argon time projection chamber

Wednesday, 23 August 2023 11:35 (35 minutes)

The fidelity of detector simulation is crucial for precision experiments, such as the Deep Underground Neutrino Experiment (DUNE) which uses liquid argon time projection chambers (LArTPCs). We can improve the detector simulation by performing dedicated calibration measurements against controlled real data and then applying them to the simulation. Using conventional calibration approaches, typically we are only able to tackle individual detector processes per measurement. However, as in LArTPCs, all the detector effects are entangled in the measured detector output. We present a differentiable simulator for a LArTPC based on a DUNE near detector prototype. It enables gradient-based optimization of the detector simulation by simultaneously fitting multiple relevant modeling parameters. The use of the differentiable simulator allows in-situ calibration which provides natural consistency between the calibration measurements and simulation application. This work also paves a way to solve "inverse detector simulation" challenge which aims to map the detector output to detector physics quantities of interest.

Primary author: CHEN, Yifan (SLAC)

Presenter: CHEN, Yifan (SLAC)

Session Classification: Session 3

Contribution ID: **26** Type: **Individual Talk**

Extracting the $\cos 2\phi$ Asymmetry in the Drell-Yan process using Deep Neural Networks

Thursday, 24 August 2023 11:20 (35 minutes)

Muon-pair production in pp collisions through the Drell-Yan process provides an important tool for studying the internal quark-gluon structure of the nucleon. Precisely measuring the $\cos 2\phi$ asymmetry, where ϕ represents the azimuthal angle of the $\mu^+\mu^-$ pair in the Collins-Soper frame, provides valuable insights into the proton's structure. Conventional methods for extracting the $\cos 2\phi$ asymmetry typically employ unfolding techniques to map detector measurements to the particle level, followed by multi-dimensional fitting procedures. However, these traditional approaches face challenges in higher-dimensional phase spaces due to complex matrix operations. To overcome these limitations and improve parameter estimation accuracy, we propose a novel approach utilizing Deep Neural Networks (DNNs). DNNs excel in approximating nonlinear functions, making them well-suited for representing the full phase space in parameter extraction. We extract the $\cos 2\phi$ asymmetry directly from the detector measurements using neural networks as likelihood functions, which are parametrized with Drell-Yan angular coefficients. In our presentation, we will discuss the design of the neural network architecture, elaborate on our training strategies, and outline our plans to achieve conclusive results using this novel approach with SeaQuest experiment data.

Primary author: NAWARATHNE, Dinupa (New Mexico State University)

Presenter: NAWARATHNE, Dinupa (New Mexico State University)

Session Classification: Session 5

Contribution ID: **27** Type: **Individual Talk**

Towards Self-Supervised Learning for Neutrino Experiments (remote)

Friday, 25 August 2023 09:00 (25 minutes)

Deep learning models for reconstruction in LArTPC neutrino data have become ubiquitous and have been successfully applied to real analyses. These models usually have to be trained from scratch depending on the task and do not take into account symmetries or systematic uncertainties.

Following advances in contrastive learning we show how such a method can be applied to sparse 3D LArTPC data, by demonstrating it on the PILArNet open dataset. The contrastive learning framework allows us to extract representations from the data that are invariant to underlying symmetries and systematic uncertainties. Using contrastive learning, we pretrain a sparse submanifold convolutional model based on ConvNeXT v2. We showcase the flexibility and efficacy of the method by fine-tuning the pretrained model on classification and semantic segmentation tasks, showing it surpasses conventional deep learning methods.

Primary author: RADEV, Radi (CERN)

Presenter: RADEV, Radi (CERN)

Session Classification: Session 7

Contribution ID: **28** Type: **Collaboration Talk**

Reconstructing Inelasticity in IceCube using Deep Neural Networks

Tuesday, 22 August 2023 10:00 (35 minutes)

The IceCube neutrino observatory is a gigaton-scale water Cherenkov detector located at the South Pole instrumented with 5160 optical modules in a cubic kilometer of ice. When a high energy neutrino undergoes deep inelastic scattering, the inelasticity of the interaction is the fraction of energy deposited in the hadronic shower to the incoming neutrino energy. For a muon neutrino event, where the interaction vertex is contained within the instrumented detector volume, it is possible to measure the energy of the shower as well as the energy of the outgoing muon–which sum to the energy of the incoming neutrino. We show that by using deep neural networks trained on PMT pulse information from IceCube's optical modules, we can reconstruct the components of the event's energy partitioned into the hadronic shower and outgoing muon and extract the inelasticity of the interaction.

Primary author: WEIGEL, Philip (Massachusetts Institute of Technology)

Presenter: WEIGEL, Philip (Massachusetts Institute of Technology)

Session Classification: Session 1

Contribution ID: **29** Type: **Individual Talk**

Variational Studies of nEXO's Topological Discriminator

Thursday, 24 August 2023 09:45 (25 minutes)

The nEXO Experiment is a search for neutrinoless double beta decay in 136Xe using a 5-ton liquid xenon time projection chamber. Machine learning is employed in nEXO's analysis as a deep neutral network discriminator to identify gamma ray backgrounds, which are distinguished from double beta decays due to their high prevalence of multiple interaction sites. This talk provides a deeper overview of the mechanisms involved in nEXO's topological discriminator and recent studies relating to its role in analysis.
nEXO's topological discriminator is well suited to the high-dimensional data collected by charge channels. A recent study of varied RMS noise on charge collection channels measured the performance of a network using simulated waveforms, demonstrating the robustness of nEXO's topological discriminator under varied RMS noise.
The current plan for nEXO's topological discriminator consists of using simulated waveforms to train the network and then use it in the analysis of detector data. In order to improve the fidelity of input training data, nEXO would like to use real detector waveforms to train its neural network. An early plan to do so is introduced, which uses gammas during calibration periods and a selective mix of beta and gamma events from physics data to train the network. Simulated waveforms were used to explore this approach by generating a mixed set of beta and gamma events trained against a set of pure gamma events to evaluate the viability of this approach.

LLNL-ABS-852238
This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI). This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Primary author: Mr SCHWARTZ, Scott (LLNL)

Presenter: Mr SCHWARTZ, Scott (LLNL)

Session Classification: Session 5

Contribution ID: **30** Type: **Individual Talk**

NuGraph2: A Graph Neural Network for Event Reconstruction in Liquid Argon Time Projection Chambers

Tuesday, 22 August 2023 16:15 (25 minutes)

We present NuGraph2, a Graph Neural Network (GNN) for reconstruction of liquid argon time projection chamber (LArTPC) data, developed as part of the ExaTrkX project. We discuss the network architecture, a multi-head attention message passing network that classifies detector hits according to the particle type that produced them. By utilizing a heterogeneous graph structure with independent subgraphs for each 2D plane's hits and for 3D space points, the model achieves a consistent description of the neutrino interaction across all planes.

Performance results will be presented based on publicly available samples from MicroBooNE. These will include both physics performance metrics, achieving ~95% accuracy for semantic segmentation of detector hits. We will also discuss applications of the network for additional LArTPC reconstruction tasks, such as event classification, background hit rejection, vertex reconstruction and instance segmentation (clustering).

We will also summarise a suite of general-purpose tools developed to provide boilerplate solutions for common ML workflow problems, and discuss prospects for integration in the data processing chains of experiments.

Primary author: Dr HEWES, V (University of Cincinnati)

Presenter: Dr HEWES, V (University of Cincinnati)

Session Classification: Session 2

Contribution ID: **31** Type: **not specified**

Opening remark

Tuesday, 22 August 2023 09:00 (15 minutes)

Presenter: WONGJIRAD, Taritree (Tufts University)

Session Classification: Session 1

Contribution ID: **33** Type: **not specified**

Closing

Friday, 25 August 2023 12:10 (20 minutes)

Presenter: TERAO, Kazuhiro (SLAC)

Session Classification: Session 7

Contribution ID: **34** Type: **not specified**

End-to-End, Machine-Learning-Based Data Reconstruction Chain for the Short Baseline Neutrino Program

Tuesday, 22 August 2023 11:30 (35 minutes)

Recent leaps in Computer Vision (CV), made possible by Machine Learning (ML), have motivated a new approach to the analysis of particle imaging detector data. Unlike previous efforts which tackled isolated CV tasks, this talk introduces an end-to-end, ML-based data reconstruction chain for Liquid Argon Time Projection Chambers (LArTPCs), the state-of-the-art in precision imaging at the intensity frontier of neutrino physics. The chain is a multi-task network cascade which combines voxel-level feature extraction using Sparse Convolutional Neural Networks and particle superstructure formation using Graph Neural Networks. Each individual algorithm incorporates physics-informed inductive biases, while their collective hierarchy enforces a causal relashionship between them. The output is a comprehensive description of an event that may be used for high-level physics inference. The chain is end-to-end optimizable, eliminating the need for time-intensive manual software adjustments. The short baseline neutrino (SBN) program aims to clarify neutrino flux anomalies observed in previous experiments by leveraging two LArTPCs (ICARUS and SBND) placed at different distances relative to the booster neutrino beam (BNB) target. This presentation highlights the progress made in leveraging the ML-based reconstruction chain to achieve the SBN physics goals which will pave the way for the future success of the Deep Underground Neutrino Experiment (DUNE).

Presenter: DRIELSMA, Francois (SLAC)

Session Classification: Session 1

Contribution ID: **35** Type: **not specified**

Deep Learning applications for electron neutrino reconstruction in the ICARUS experiment

Tuesday, 22 August 2023 14:10 (25 minutes)

The ICARUS T600 detector is a liquid argon time projection chamber (LArTPC) installed at Fermilab, aimed towards a sensitive search for possible electron neutrino excess in the 200-600 MeV region. To investigate numu to nue appearance signals in ICARUS, a fast and accurate algorithm for selecting electron neutrino events from a background of cosmic interactions is required. We present an application of the general-purpose deep learning based reconstruction algorithm developed at SLAC to the task of electron neutrino reconstruction in the ICARUS detector. We demonstrate its effectiveness using a simulation dataset containing nue events and out-of-time cosmic interactions generated using the CORSIKA software. In addition, we compare the selection efficiency/purity and reconstructed energy resolution across different initial neutrino energy ranges, and discuss current efforts to improve reconstruction of low energy neutrino events.

Presenter: KOH, Dae (SLAC)

Session Classification: Session 2

Contribution ID: **36** Type: **Collaboration Talk**

Deep Learning for Water Cherenkov Detectors

Wednesday, 23 August 2023 09:15 (35 minutes)

Cherenkov radiation is widely used in particle physics and astro-physics since its discovery in the early 20th century.
Numerous waterCherenkov detectors have been deployed, with more in preparation,for various physics programs such as nucleon decay search and preciseneutrino measurements. Like all other experiments, efficiently quan-tifying detector systematic uncertainties poses a significant chal-lengedue to their intricate impacts on the observed physics. This challengebecomes even more crucial in the next generation experiments, whereextensive data statistics will make the systematic effects the domi-nant uncertainties. Thankfully, the rapid advancements in artificialintelligence and deep learning offer promising solutions to tackle thesechallenges.

Presenter: XIA, Junjie (IPMU)

Session Classification: Session 3

Contribution ID: **37** Type: **not specified**

MAJORANA demonstrator data release

Friday, 25 August 2023 11:55 (15 minutes)

Presenter: LI, Aobo (Boston University)

Session Classification: Session 7