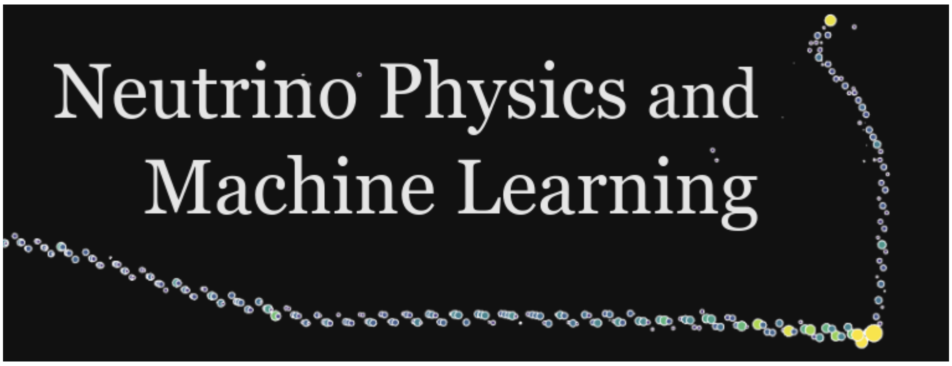
Neutrino Physics and Machine Learning (NPML)



Report of Contributions

Contribution ID: **2** Type: **Individual talk**

A Machine Learning Approach to Study the Neutrino Charged-current Interaction on 127I

Tuesday, 14 July 2020 13:40 (25 minutes)

An inclusive measurement of the cross section of the neutrino charged-current interactions on 127I will help study the quenching of gA , the axial-vector coupling constant, which determines the rate of neutrinoless double beta decays. At the Los Alamos Meson Production Facility (LAMPF), an exclusive measurement was made but with a large statistical error. To make an inclusive and more accurate measurement, a 185 kg NaI[Tl] prototype was deployed by the COHERENT collaboration. To reduce the major background, cosmic rays, a machine learning model based on a convolutional neural network (CNN) is being developed. The model, tested with simulations, can remove 78% of the backgrounds while preserving 77% of the cc signals.

Primary author: Mr AN, Peibo (Duke University)

Presenter: Mr AN, Peibo (Duke University)

Session Classification: Day 2 Afternoon

Contribution ID: **4** Type: **A collaboration/project summary talk**

Summary of Machine Learning Applications for the COHERENT Collaboration

Tuesday, 14 July 2020 13:00 (40 minutes)

The COHERENT collaboration utilizes a suite of detectors to search for coherent elastic neutrino-nucleus scattering (CEvNS) and associated backgrounds at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. Measurement of the low-energy nuclear recoil signature of CEvNS events necessitates the identification and rejection of environmental and detector-intrinsic backgrounds. Machine learning for purpose of event identification is being investigated in several COHERENT detectors. An overview of the techniques being used and the results of their application to experimental data will be presented.

Primary author: DAUGHHETEE, Jacob (University of Tennessee)

Presenter: DAUGHHETEE, Jacob (University of Tennessee)

Session Classification: Day 2 Afternoon

Contribution ID: **5** Type: **Individual talk**

Using Sparse Convolutional Neural Networks in MicroBooNE

Friday, 10 July 2020 11:25 (25 minutes)

The MicroBooNE experiment employs a Liquid Argon Time Projection Chamber (LArTPC) detector to measure sub-GeV neutrino interactions from the muon neutrino beam produced by the Booster Neutrino Beamline at Fermilab. Neutrino oscillation measurements, such as those performed in MicroBooNE, rely on the capability to distinguish between different flavors of neutrino interactions. Deep Convolutional Neural Networks (CNNs) present high success for these tasks; however, due to the large sparsity of the data ($<1\%$ pixels are non-zero), a naive approach of applying CNNs becomes highly inefficient in both computation time and memory resources. Recently Submanifold Sparse Convolutional Networks (SSCNs) have been proposed to address this challenge and have successfully applied to analyze large LArTPC images in MicroBooNE with orders of magnitude improvement in computing resource usage. In this poster, I will present the performance of SSCNs on the task of Semantic Segmentation applied in the analysis of simulated MicroBooNE data.

Primary author: ITAY, Ran (WEIZMANN INST.)

Presenter: ITAY, Ran (WEIZMANN INST.)

Session Classification: Day 1 Morning

Contribution ID: **6** Type: **A collaboration/project summary talk**

ML challenges in Theia and WBLS

Friday, 10 July 2020 13:00 (40 minutes)

Theia is a proposed 25-100 kiloton multi-purpose neutrino detector using novel target materials and advanced light detection techniques to address a wide range of neutrino and rare event physics. Key to this is the ability to separate scintillation and Cherenkov light using high-precision timing photo-sensors. Water-based-liquid-scintillator (WBLS) can be used to optimise the relative ratio of both light species for this purpose. This allows to combine high energy resolution with directional information while providing unique tracking and particle-identification capabilities. Machine Learning (ML) offers a wide range of tools to unlock this potential.
In this talk we will highlight some of these ML applications and point out future directions.

Primary author: Dr WONSAK, Björn (University of Hamburg)

Presenter: Dr WONSAK, Björn (University of Hamburg)

Session Classification: Day 1 Afternoon

Contribution ID: **7** Type: **Individual talk**

Neutrino energy reconstruction with a regression CNN in the DUNE far detector

Wednesday, 22 July 2020 10:40 (25 minutes)

In the framework of three-active-neutrino mixing, the charge parity phase, the neutrino mass ordering and the octant of θ_{23} remain unknown. The primary goal of DUNE is to address these questions by measuring the oscillation patterns of ν_μ and $\bar{\nu}_\mu$ over a range of energies spanning the first and second oscillation maxima, which requires precisely reconstructed neutrino energy spectra. However, energy reconstruction of neutrino events in DUNE presents many challenges due to missing energies caused by argon impurities, nonlinear energy response of the detector, etc. One way of approaching this problem is using machine learning to reconstruct neutrino energies from pixel map images of interactions in the detector. In this talk, a regression convolutional neural network with a custom architecture designed to reconstruct neutrino energies will be presented. Comparing to a traditional method, it shows considerable performance improvements for both ν_e and ν_μ scenarios.

Primary author: Dr WU, Wenjie (University of California, Irvine)

Presenter: Dr WU, Wenjie (University of California, Irvine)

Session Classification: Day 4 Morning

Contribution ID: **8** Type: **A collaboration/project summary talk**

Machine learning techniques in ANNIE

Wednesday, 22 July 2020 13:00 (40 minutes)

The Accelerator Neutrino Neutron Interaction Experiment (ANNIE) is a 26-ton Gd-doped water Cherenkov detector installed in the Booster Neutrino Beam (BNB) at Fermilab. The experiment aims to make a unique measurement of neutron yield from neutrino-nucleus interactions and to perform R&D for the next generation of water-based neutrino detectors. To realise these goals the ANNIE collaboration has developed several reconstruction techniques. Boosted DecisionTrees and Deep Learning are used to reconstruct the muon and neutrino energy and Neural Networks and CNNs are used for particle identification and ring counting. In this talk, we discuss the machine learning-based techniques used in the ANNIE experiment.

Primary author: Dr DRAKOPOULOU, Evangelia (University of Edinburgh)

Presenter: Dr DRAKOPOULOU, Evangelia (University of Edinburgh)

Session Classification: Day 4 Afternoon

Contribution ID: **9** Type: **Individual talk**

Graph neural networks for 3D voxel classification in scintillator-based trackers

Tuesday, 14 July 2020 10:25 (25 minutes)

Deep learning tools are being used extensively in high energy physics and are becoming central in the reconstruction of neutrino interactions in particle detectors. Some neutrino experiments are already using them, for example, for distinguishing among different neutrino topologies.

In this talk, we report on the performance of a graph neural network (GNN) approach in assisting with particle flow event reconstruction. In order to study the potential of GNNs for neutrino event reconstruction, we have developed a GNN - inspired by GraphSAGE algorithm - and tested it on the Super Fine-Grained Detector (SuperFGD), a new fully active 2-ton target made of about 2,000,000 optically isolated 1x1x1cm^3 scintillator cubes, read out by three-wavelength shifting fibres. It will be installed at the Near Detector site of the T2K experiment in 2022.
Despite the usage of optical reflectors, scintillator detectors show a small amount of light leakage between adjacent volumes, named cross-talk, that can worsen the separation between particle tracks and introduce more ambiguities (ghosts) in the 3D reconstruction. The GNN has been designed for classifying the 3D reconstructed voxels into three categories: particle track, cross-talk and ghost-like. It has been tested on Monte-Carlo simulated events showing promising classification performance both in purity and efficiency. The robustness of GNN has been tested by training it on diverse samples.

Primary authors: Mr ALONSO MONSALVE, Saul (CERN); Dr SGALABERNA, Davide (ETHZ); Dr WHITEHEAD, Leigh Howard (University of Cambridge); Mr PINA OTEY, Sebastian; Dr LUX, Thorsten; Mrs DOUQA, Dana; Mr JESUS-VALLS, Cesar; Prof. SANCHEZ, Federico

Presenter: Mr ALONSO MONSALVE, Saul (CERN)

Session Classification: Day 2 Morning

Contribution ID: **10** Type: **Individual talk**

A Convolutional Neural Network for Multiple Particle Identification in the MicroBooNE LArTPC

Friday, 10 July 2020 11:50 (25 minutes)

MicroBooNE has accumulated data in a 1E21 POT neutrino beam over five years to test the excess of low energy electron neutrino-like events observed by MiniBooNE. To this end, we have explored the use of a new hybrid analysis chain that includes both conventional and machine learning reconstruction algorithms to identify events with the exclusive 1-proton-1-electron signal topology. The multiple-particle-identification (MPID) network we developed is an important application of convolutional neural networks that takes a reconstructed image as input, and provides simultaneous probabilities of having a proton, electron, gamma, muon or charged pion in the image. MPID shows a promising ability to separate the physical features that distinguish interactions. In this poster, we present the highlights of MPID training and performance in both simulated and real datasets.

Primary author: AN, Rui (Illinois Institute of Techonology)

Presenter: AN, Rui (Illinois Institute of Techonology)

Session Classification: Day 1 Morning

Contribution ID: **11** Type: **Individual talk**

Demonstration of background rejection using deep neural networks in the NEXT experiment

Tuesday, 21 July 2020 10:40 (25 minutes)

The NEXT (Neutrino Experiment with a Xenon TPC) experiment searches for neutrinoless double-beta decay in 136Xe using a time projection chamber (TPC) filled with enriched xenon gas at high pressure. NEXT can reconstruct the extended ionization tracks left by electrons in the gas. Using this information we can select events with two electrons with a common vertex (double beta decay) from the background of single electron events (mostly produced by the Compton scatters of high energy gammas). Here we present the use of neural networks for this discrimination. Using data from the NEXT-White detector and a model of signal using pair-production events at 1.59 MeV we will show that a deep convolutional network, trained on Monte Carlo events, can provide good discrimination between one- and two-electron tracks. We also explore scalability of the network to larger detector volumes via sparse convolutions and discuss measures for ensuring robustness of the network despite differences in Monte Carlo simulation and experimentally acquired data.

Primary authors: Dr KEKIC, Marija (IGFAE); Dr RENNER, Joshua (IGFAE)

Presenter: Dr KEKIC, Marija (IGFAE)

Session Classification: Day 3 Morning

Contribution ID: **12** Type: **Individual talk**

Deep Learning Classifier for Low-Energy Events in IceCube

Friday, 24 July 2020 13:40 (25 minutes)

Tau appearance from neutrino oscillations of atmospheric muon neutrinos is studied by the DeepCore subarray, the densely-instrumented region of IceCube, an ice-Cherenkov neutrino detector 1.5 kilometers below the surface of the South Pole. These studies probe the unitarity of the PMNS matrix. Distinguishable event signatures in this region include track-like and shower-like events. Because the contribution of tau neutrinos manifests as a statistically significant excess of shower-like events, accurate event classification is crucial. However, at the low energies relevant to the oscillation maximum, separation of tracks and showers is challenging. This talk will show an ongoing study of a deep learning event classifier that currently achieves an accuracy comparable to that of the currently used method, with still large room for improvement. We show that DNNs can learn complex features in DeepCore data at hit level (i.e., not relying on reconstructed quantities) that differentiate the signal types.

Primary author: PRADO RODRIGUEZ, Maria (University of Wisconsin-Madison)

Presenter: PRADO RODRIGUEZ, Maria (University of Wisconsin-Madison)

Session Classification: Day 5 Afternoon

Contribution ID: **13** Type: **Individual talk**

Optimizing a CNN to Reconstruct Low Energy IceCube Neutrino Events

Friday, 24 July 2020 14:05 (25 minutes)

The IceCube Neutrino Observatory, located at the South Pole, instruments a cubic kilometer of ice with 5160 optical modules that are used to detect astrophysical and atmospheric neutrinos. Near the lowest energies that IceCube can resolve, at the 10s of GeV-scale, these events leave a Cherenkov signature that only a few optical modules will record. Thus, these events are difficult to accurately reconstruct. Improving the speed and resolution of low energy event reconstruction in IceCube is important to advance analyses such as measuring the neutrino oscillation parameters. This work focuses on applying a convolution neural network (CNN) to reconstruct low energy events in IceCube. The CNN is optimized to handle the sparse, low energy data with the aim to reconstruct the energy and direction of neutrino events. Some of these optimizations will be discussed along with showing the current results for the resolution.

Primary author: MICALLEF, Jessie (Michigan State University)

Presenter: MICALLEF, Jessie (Michigan State University)

Session Classification: Day 5 Afternoon

Contribution ID: **14** Type: **A collaboration/project summary talk**

DIDACTS (Data-Intensive Discovery Accelerated by Computational Techniques for Science)

Tuesday, 21 July 2020 10:00 (40 minutes)

DIDACTS (Data-Intensive Discovery Accelerated by Computational Techniques for Science) is a collaboration of physics and machine learning experts with an overall goal of incorporate scientific knowledge into machine learning and data science methods in the context of scientific disciplines. As part of DIDACTS'research program, we are looking into the challenging problem of Dark Matter direct detection using XENON1T as test bed. The core principle of DIDACTS is that many particle physics experiments lend themselves to 'graphical' data analysis as the data is often hierarchical and irregular. In this talk we will highlight some of DIDACTS'projects such as; graphical convolutional neural networks, quasi-supervised learning via inverse problem regularization, graph learning, and having per-event reconstruction uncertainties using graphical models.

Primary author: HIGUERA, Aaron (Rice University)

Presenter: HIGUERA, Aaron (Rice University)

Session Classification: Day 3 Morning

Contribution ID: **15** Type: **A collaboration/project summary talk**

Machine Learning Research and Applications in IceCube

Friday, 24 July 2020 13:00 (40 minutes)

The field of machine learning has become increasingly important over the last years and now constitutes a vital contribution to the physics output of experiments such as IceCube. IceCube is a neutrino telescope situated at the geographic South Pole, instrumenting a cubic kilometer of glacial ice. Atmospheric and astrophysical neutrinos are indirectly measured via Cherenkov radiation of charged secondary particles. Key challenges to the success of IceCube are background suppression, topology classification, and event reconstruction. Machine learning has been widely adopted within IceCube, not only to tackle these challenges, but also in the development of analysis methodology. Dedicated methods that leverage domain knowledge can further maximize the physics potential of the IceCube detector. This talk will provide an overview of machine learning research and applications in IceCube.

Primary author: HUENNEFELD, Mirco (TU Dortmund)

Presenter: HUENNEFELD, Mirco (TU Dortmund)

Session Classification: Day 5 Afternoon

Contribution ID: **16** Type: **A collaboration/project summary talk**

Machine Learning in the NOvA Experiment

Tuesday, 21 July 2020 13:00 (40 minutes)

NOvA is a long-baseline neutrino experiment primarily studying neutrino oscillations in the NuMI beam from Fermi National Laboratory (FNAL), USA. It consists of two functionally identical, finely granulated detectors which are separated by 809 km and situated 14.6 mrad off the NuMI beam axis from FNAL. A new set of oscillation results were shown at the Neutrino 2020 conference. Key to these measurements was the use of machine learning algorithms that use topological features for the reconstruction of neutrino interaction flavor and particle identification. For this analysis, the NOvA Collaboration made several significant improvements to these algorithms. Some of the highlights include a new, optimized architecture and improved training techniques which enhance our performance for physics analyses and reduce systematic bias, as well as a network designed to filter out cosmic events at the earliest possible stage of the reconstruction process. NOvA has also begun developing techniques for the next generation of analyses. A brief outline of some of these prospects will be discussed.

Primary author: WARBURTON, Karl (Iowa State University)

Presenter: WARBURTON, Karl (Iowa State University)

Session Classification: Day 3 Afternoon

Contribution ID: **17** Type: **Individual talk**

Enhancing Neutrino Event Reconstruction with Pixel-Based 3D Readout for Liquid Argon Time Projection Chambers

Wednesday, 22 July 2020 11:30 (25 minutes)

In this talk we will show the potential improvements in neutrino event reconstruction that a 3D pixelated readout could offer over a 2D projective wire readout for liquid argon time projection chambers. We simulated and studied events in two generic, idealized detector configurations for these two designs, classifying events in each sample with deep convolutional neural networks to compare the best 2D results to the best 3D results. In almost all cases we found that the 3D readout provides better reconstruction efficiency and purity than the 2D projective wire readout, with the advantages of 3D being particularly evident in more complex topologies, such as electron neutrino charged current events. We conclude that the use of a 3D pixelated detector could significantly enhance the reach and impact of future liquid argon TPC experiments physics program, such as DUNE.

Primary authors: ADAMS, Corey (Argonne National Laboratory); Dr DEL TUTTO, Marco (Fermilab)

Presenter: Dr DEL TUTTO, Marco (Fermilab)

Session Classification: Day 4 Morning

Contribution ID: **18** Type: **A collaboration/project summary talk**

Machine Learning Techniques in Event Reconstruction and Classification for Cyclotron Radiation Emission Spectroscopy Signals in Project 8

Tuesday, 14 July 2020 14:05 (40 minutes)

Project 8 is developing Cyclotron Radiation Emission Spectroscopy (CRES) on the beta-decay spectrum of tritium for the measurement of the absolute neutrino mass scale. CRES is a frequency-based technique that aims to probe the endpoint in the tritium energy spectrum with a final sensitivity of 0.04 eV. Current studies are performed on monoenergetic electrons from a gaseous \textsuperscript{83\textit{m}}Kr calibration source and beta-decay electrons from molecular tritium; the first ever CRES tritium spectrum was recently obtained and presented at Neutrino2020. We discuss the event reconstruction process which leads us from frequency measurements to an energy spectrum with special focus on the machine learning techniques developed to classify (Support Vector Machine) and reconstruct (Convolutional Neural Network) CRES signals with strong precision and accuracy.

Primary author: Mr SALDAÑA, Luis (Yale University)

Presenter: Mr SALDAÑA, Luis (Yale University)

Session Classification: Day 2 Afternoon

Contribution ID: **19** Type: **Individual talk**

Regression CNNs for Energy Reconstruction in the NOvA Experiment

Tuesday, 21 July 2020 13:40 (25 minutes)

NOvA is an accelerator neutrino experiment with an 810 km baseline. Using the NuMI beam from Fermilab, it measures electron neutrino appearance and muon neutrino disappearance at its far detector. NOvA has embraced a wide range of deep learning methods. Here we will focus on energy regression CNNs. NOvA has developed a regression CNN that takes the raw cells from the detector as inputs, and outputs an estimate of the electron neutrino event energy. The resolution of this CNN outperforms that of the traditional method, and also has improved systematic uncertainty. NOvA is also experimenting with regression CNNs for other energy estimation tasks.

Primary author: JARGOWSKY, Ben (University of California, Irvine)

Presenter: JARGOWSKY, Ben (University of California, Irvine)

Session Classification: Day 3 Afternoon

Contribution ID: **20** Type: **Individual talk**

ML Methods Investigation for Hyper-K Neutron Capture Classification

Friday, 24 July 2020 11:05 (25 minutes)

Hyper-Kamiokande is the proposed next generation Water Cherenkov neutrino detector in Kamioka, Japan. Based on the design of Super-Kamiokande, Hyper-K will have an order of magnitude larger fiducial mass, enabling the survey of topics in neutrino physics on a broader scale. The intermediate Water Cherenkov detector (IWCD) near the J-PARC beam in Tokai aims at reducing systemic uncertainty in Hyper-K by spanning the range of off-axis beam angles from one to four degrees to constrain the relationship between lepton kinematics and neutrino energy. In this report, statistical and machine learning techniques are investigated to optimize the classification of neutron capture events from background radiation for IWCD-simulated data. This includes a likelihood-based approach, gradient boosting methods XGBoost and LightGBM, a multi-layer perceptron model and a graph neural network (GNN). Event differentiation is also explored through the lens of event isotropy through calculation of beta parameters.

Primary author: STUBBS, Matthew (University of Winnipeg)

Presenter: STUBBS, Matthew (University of Winnipeg)

Session Classification: Day 5 Morning

Contribution ID: **21** Type: **Individual talk**

A Generative Neural Network for Water Cherenkov Reconstruction

Friday, 24 July 2020 11:30 (25 minutes)

Deep neural networks are an area of very active research in neutrino event reconstruction. On the other hand, state-of-the-art reconstruction methods for water Cherenkov detectors use more traditional maximum-likelihood approaches. Here we present initial studies for a convolutional neural network that generates probability density functions for the data (hit charge and time) observed at each photosensor in water Cherenkov detectors. Such a neural network can be used to incorporate high-performance deep learning methods in existing maximum-likelihood reconstruction algorithms. We will discuss merits of this approach, its current status and future plans, such as the development of bespoke loss functions and adversarial training.

Primary author: VILELA, Cristovao (Stony Brook University)

Presenter: VILELA, Cristovao (Stony Brook University)

Session Classification: Day 5 Morning

Contribution ID: **22** Type: **A collaboration/project summary talk**

Machine Learning based reconstruction for Hyper Kamiokande

Friday, 24 July 2020 10:00 (40 minutes)

We present initial developments of ML based event reconstruction for water Cherenkov detectors in the context of Hyper Kamiokande. Using ML, we aim to exploit additional spatial and directional information from higher granularity PMTs developed for HyperK to improve on existing reconstruction performance and to enable new measurements that are very challenging in conventional maximum-likelihood fitters. Here, we present several ongoing works, using standard CNN, a new CNN architecture, and other types of networks to efficiently handle topology and geometry of cylindrical detectors. Applications of these networks to particle identification are presented, including electron / gamma separation at higher energies and neutron capture / radioactive decay separation at lower energies. We also present our future plans for additional applications, including generative networks with unsupervised and semi-supervised approaches.

Primary authors: HYPER KAMIOKANDE COLLABORATION; BERNS, Lukas (Tokyo Institute of Technology)

Presenter: BERNS, Lukas (Tokyo Institute of Technology)

Session Classification: Day 5 Morning

Contribution ID: **23** Type: **Individual talk**

Estimating the Impact of Neutrino Interaction Mismodeling in DUNE with Multivariate Event Reweighting

Wednesday, 22 July 2020 11:05 (25 minutes)

Next generation long-baseline experiments will measure neutrino mixing parameters with unprecedented precision, requiring stringent constraints on systematic uncertainties. We present the methods used in the recently published DUNE technical design report to test the robustness of the experiment with respect to variations of the neutrino interaction model. A multivariate method was used to reweight the existing DUNE simulated event sample to alternative interaction models, including a modification of the nominal model designed specifically to induce a bias in reconstructed neutrino energy. These reweighting schemes are used in oscillation analysis studies to demonstrate the ability of the DUNE near detector complex to resolve bias-inducing model variations, in particular by taking data at several positions with respect to the beam axis.

Primary author: VILELA, Cristovao (Stony Brook University)

Presenter: VILELA, Cristovao (Stony Brook University)

Session Classification: Day 4 Morning

Contribution ID: **24** Type: **Individual talk**

Proposal-free Deep Sparse Convolutional Neural Network for 3D Pixel Clustering

Friday, 10 July 2020 14:45 (25 minutes)

High resolution particle imaging detectors can record full details of charged particle interactions, and opens a door to high precision neutrino oscillation measurements. In order to maximize the physics output, however, development of high quality data reconstruction techniques is critical. One of the challenging data reconstruction task is clustering of pixels to identify individual particles in an image. In the field of Computer Vision, proposal-based instance segmentation techniques such as Mask R-CNN has become increasingly popular and known to work well on photographs. However, these techniques have been developed for photographs that are severely different from image of particle trajectories and other science data, and can inherently suffer from challenges including an occlusion issue. The researchers in the Computer Vision has made significant progress on proposal-free instance segmentation techniques that are shown to work extremely well on science domain image data similar to ours. We have implemented a proposal-free instance segmentation algorithm into an end-to-end, deep learning based full data reconstruction chain developed by SLAC ML group. In this talk, I will describe the algorithm design and performance studied using PILArNet, the public LArTPC particle simulation dataset.

Primary author: KOH, Dae (SLAC)

Co-author: TERAO, Kazuhiro (SLAC)

Presenter: KOH, Dae (SLAC)

Session Classification: Day 1 Afternoon

Contribution ID: **25** Type: **Individual talk**

Full Event Reconstruction on NOvA using Instance Segmentation

Tuesday, 21 July 2020 14:30 (25 minutes)

The NOvA experiment is a long baseline neutrino oscillation experiment measuring neutrino oscillations and cross sections using the NuMI beam at Fermilab. Reconstructing particles produced in neutrino interactions provides the basis for neutrino energy estimation and final state identification for cross section measurements and interaction model tuning. This talk will present an end-to-end technique for reconstructing a neutrino interaction using instance segmentation based on Mask R-CNN. This technique simultaneously reconstructs particle hit clusters and classifies the particle identity. This has now been incorporated into NOvA's analysis framework and shows improvement in the number of particles that get reconstructed and in the purity of reconstructed particle clusters.

Primary author: GROH, Micah (Indiana University Bloomington)

Presenter: GROH, Micah (Indiana University Bloomington)

Session Classification: Day 3 Afternoon

Contribution ID: **26** Type: **Individual talk**

Neutrino Energy Reconstruction with Recurrent Neural Networks at NOvA

Tuesday, 21 July 2020 14:05 (25 minutes)

In this talk we discuss application of the recurrent neural networks to the task of energy reconstruction at the NOvA experiment. NOvA is a long-baseline accelerator based neutrino oscillation experiment that holds a leading measurement of the Δm^2_{32} oscillation parameter. In order to achieve good estimation of the oscillation parameters it is imperative to have a good neutrino energy estimation algorithm. We have developed a new energy estimation algorithm that is based on a recurrent neural network. The new energy estimator has better performance than the previous NOvA energy estimation algorithm, and it is less affected by some of the major NOvA systematics. Using this new energy estimator has potential to significantly improve NOvA sensitivity to the oscillation parameters.

Primary author: TORBUNOV, Dmitrii (University of Minnesota, Twin Cities)

Presenter: TORBUNOV, Dmitrii (University of Minnesota, Twin Cities)

Session Classification: Day 3 Afternoon

Contribution ID: **27** Type: **Individual talk**

Machine Learning Applications for Reactor Antineutrino Detection at PROSPECT

Tuesday, 14 July 2020 11:15 (25 minutes)

PROSPECT is an antineutrino detector located above ground at the High-Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). The energy spectrum of antineutrinos emitted from the reactors is measured by using a delayed coincidence technique through the inverse-beta-decay reaction (IBD). The ORNL group is currently exploring several applications of machine learning techniques for the reconstruction and analysis of antineutrino events. In this talk, an overview of these efforts will be presented. Specifically, the use of the individual distribution of the observables of positron and neutron signals in IBD's can be used as input to train a neural network to discriminate between true IBD interactions and accidental correlations. Furthermore, we explore the possibility of using machine learning techniques to optimize the pulse-shape discrimination (PSD) variable used for particle classification. We designed an encoder-decoder architecture for sequence prediction based on recurrent neural networks (RNNs). This method will allow us to match detector pulses to reconstruct the IBD interaction.

Primary author: DELGADO, Andrea (Oak RIdge National Laboratory)

Presenter: DELGADO, Andrea (Oak RIdge National Laboratory)

Session Classification: Day 2 Morning

Contribution ID: **28** Type: **Individual talk**

NEXT Ton-Scale Sensitivity using Sparse Convolutional Neural Networks

Tuesday, 21 July 2020 11:05 (25 minutes)

The NEXT Collaboration is currently designing and performing R&D for a ton-scale detector capable of observing neutrinoless double beta decay. NEXT utilizes a high pressure gaseous xenon TPC with an electroluminescent region to amplify the signal from the drift electrons, and has successfully built and collected data with several smaller scale prototypes. The current expected sensitivity of the ton-scale detector is based on traditional analysis cuts that have been developed and tested on data from the currently running 10~kg detector. We will present recent studies which seek to improve the neutrinoless double beta decay signal selection efficiency and background rejection of simulated data in a ton-scale detector based on a sparse convolutional neural network classifier.

Primary author: WOODRUFF, Katherine (University of Texas at Arlington)

Presenter: WOODRUFF, Katherine (University of Texas at Arlington)

Session Classification: Day 3 Morning

Contribution ID: **29** Type: **A collaboration/project summary talk**

Scalable, End-to-End Deep Learning Based Data Reconstruction Chain for 3D Particle Imaging Detectors

Friday, 10 July 2020 13:40 (40 minutes)

The field of experimental neutrino physics has entered an era of high precision measurements. In order to capture the details of neutrino interactions, high resolution particle imaging detectors, such as time projection chambers, have been developed. However, the analysis of images containing highly detailed particle trajectories and a large number of pileups remains challenging. Deep learning techniques have been explored previously for a number of tasks including whole image classification for physics analysis and some object reconstruction tasks. As part of inter-experimental collaborations, including the DeepLearnPhysics and Exa.TrkX projects, we have developed an end-to-end data reconstruction chain for 3D particle imaging detectors using sparse convolutional neural networks and graph neural networks. The architecture, designed to extract hierarchical physics features from the initial pixel-level information to the neutrino interaction identification, allows for a coherent optimization workflow which drastically saves software tuning and preparation time. This in turn makes the algorithm scalable to current and future large-scale neutrino detectors. In this talk, we give an overview of the full reconstruction chain, to be used in experiments including the SBN program and DUNE, with an emphasis on the implementation of graph neural networks for multiple data reconstruction tasks.

Primary author: DRIELSMA, Francois (SLAC)

Co-author: TERAO, Kazuhiro (SLAC)

Presenter: DRIELSMA, Francois (SLAC)

Session Classification: Day 1 Afternoon

Contribution ID: **30** Type: **A collaboration/project summary talk**

The deep learning frontiers of KamLAND-Zen

Tuesday, 14 July 2020 14:45 (40 minutes)

Neutrinoless Double Beta Decay ($0\nu\beta\beta$) is one of the major research thrusts in neutrino physics. The discovery of $0\nu\beta\beta$ would answer persistent puzzles in the standard model. KamLAND-Zen experiment is one of the leading efforts in the search of $0\nu\beta\beta$. The current data is collected from 745kg of Xe136 dissolved in liquid scintillator, a medium that emits isotropic light when particles deposit their energy into it. The light is detected with the help of 1879 photomultiplier tubes (PMTs) thereby producing a data stream made up of time and charge information. The raw PMT data provides a great platform for machine learning applications. From this perspective, the KamLAND collaboration is studying different ways to employ deep learning models. The first approach is to only analyze the PMT hit time using a recurrent neural network (RNN). The RNN approach is applied to KamLAND-Zen 400 data as an event selection cut. The other approach is to utilize a new spherical CNN model to incorporate event topology. The CNN functions as an efficiency beta vs. gamma classifier and has been trained using KamLAND-Zen 800 data. Eventually, we're aiming to build a deep learning analysis chain that can be trained jointly using MC and data.

Primary author: LI, Aobo (Boston University)

Presenter: LI, Aobo (Boston University)

Session Classification: Day 2 Afternoon

Contribution ID: **31** Type: **Individual talk**

Enabling A Deep Neural Networks based 3D LArTPC Data Reconstruction Chain for ICARUS

Friday, 10 July 2020 15:10 (25 minutes)

Liquid Argon Time Projection Chamber (LArTPC) offers high resolution (~3mm/pixel) 2D or 3D imaging of charged particles' trajectories. Deep neural networks (DNN) have been successfully applied to the data reconstruction of LArTPC. At SLAC we are building an end-to-end 3D LArTPC data reconstruction chain of algorithms, specifically designed for sparse LArTPC data. However LArTPCs come in two flavors: wire and pixel LArTPCs, that record multiple 2D projection images and 3D images respectively. In order to enable the 3D reconstruction chain for 2D imaging wire LArTPCs, 3D points must first be reconstructed. Existing 3D point reconstruction algorithms produce a large number of fake 3D hits formed by incorrect combinations of hits in 2D projection images, and the resulting 3D images of particle trajectories are difficult to analyze. In this talk, we present an efficient 3D deep convolutional neural network that disambiguates such fake 3D points from underlying true particle trajectories using the detector simulation of ICARUS, a large-scale (760-ton) LArTPC far detector for the Short Baseline Neutrino Program at Fermilab. Our method enables the application of a 3D reconstruction chain to any wire LArTPC detectors for a variety of tasks. We highlight here a pixel-level particle type classification followed by the reconstruction of a Michel electron, a commissioning analysis target for the calibration of the low energy electromagnetic showers.

Primary authors: DOMINE, Laura (Stanford University); TSANG, Patrick (SLAC); TERAO, Kazuhiro (SLAC); Dr USHER, Tracy

Presenter: TSANG, Patrick (SLAC)

Session Classification: Day 1 Afternoon

Contribution ID: **32** Type: **Individual talk**

Scalable 3D Semantic Segmentation and Point Proposal Network for large-scale high resolution particle imaging detectors

Friday, 10 July 2020 14:20 (25 minutes)

Particle imaging detectors such as Liquid Argon Time Projection Chambers offer high resolution imaging of charged particle trajectories. They are used and will be used in current and future neutrino experiments to maximize physics output from neutrino interactions. In order to understand the physics behind the neutrino-nucleus interactions, which remain poorly known today, the SLAC machine learning group has developed a deep learning based full data reconstruction chain that can produce interpretable physics output with reconstructed objects and their hierarchical correlations as evidence. In this short talk, I will describe the technical details about the part of our reconstruction chain that is responsible for extracting pixel-level feature information based on two computer vision tasks, semantic segmentation and object detection, enabling the reconstruction of the pixel-level particle type classification as well as start and end position of particle trajectories.

Primary authors: DOMINE, Laura (Stanford University); TSANG, Patrick (SLAC); TERAO, Kazuhiro (SLAC); KOH, Dae (SLAC); DRIELSMA, Francois (SLAC); LIN, Qing (SLAC); ITAY, Ran (WEIZMANN INST.); Dr USHER, Tracy

Presenter: DOMINE, Laura (Stanford University)

Session Classification: Day 1 Afternoon

Contribution ID: **33** Type: **Individual talk**

Simulation and Calibration of light response in nEXO detector using machine learning

Tuesday, 21 July 2020 11:30 (25 minutes)

nEXO is a proposed 5 tonne liquid xenon experiment which seeks to detect neutrinoless double beta decay $0\nu\beta\beta$ in Xe-136 using Time Projection Chamber (TPC) technology. The experiment will use the combination of scintillation and ionization signals to reconstruct events with an energy resolution of 1\% σ/E at the \gls{onbb} Q-value. The scintillation light will be collected by silicon photomultipliers (SiPM) around the sides of the detector, and their collection efficiency will vary as a function of event position. We will deploy a suite of calibration sources, including external γ-ray sources and internal sources dissolved in the liquid xenon. In this talk, we present the strategy for simulating and calibrating light response in the nEXO detector. We study a method for fast generation of simulated light signal which involves training a Machine Learning (ML) algorithm with detailed optical simulation data to learn the detector hit pattern as a function of event position and energy. Photon simulation data is then generated for each light detection channel as a function of event position and energy. This method is used to study requirements for the calibration of nEXO light detection system.

Primary author: Mr GAUTAM, Prakash (Drexel University)

Presenter: Mr GAUTAM, Prakash (Drexel University)

Session Classification: Day 3 Morning

Contribution ID: **34** Type: **A collaboration/project summary talk**

DL In MicroBooNE

Friday, 10 July 2020 10:45 (40 minutes)

The MicroBooNE experiment consists of liquid argon time projection chamber(LArTPC) situated in the path of the Booster Neutrino Beam (BNB) at Fermilab. The goals of the experiment are to (1) investigate the observation of an excess of a possible electron-neutrino and anti-neutrino events by the MiniBooNE experiment, (2) measure argon-nucleus cross sections, and (3) perform R&D for LArTPCs. The data from MicroBooNE, and other LArTPCs, can be naturally arranged as high-resolution images of particle tracks traversing the detector. This has spurred effort on MicroBooNE towards applying convolutional neural networks (CNNs), a type of deep learning algorithm shown to be effective in numerous computer vision problems, to our data. I'll talk about the ways in which MicroBooNE uses CNNs with a focus on recent results demonstrating their performance on real data. I'll also discuss future directions MicroBooNE is exploring to further apply CNNs.

Primary author: WONGJIRAD, Taritree (Tufts University)

Presenter: WONGJIRAD, Taritree (Tufts University)

Session Classification: Day 1 Morning

Contribution ID: **35** Type: **Individual talk**

Normalizing flows applications in neutrino physics: likelihood-free inference and efficient Monte Carlo generation

Tuesday, 14 July 2020 10:50 (25 minutes)

Normalizing flows present a powerful framework to sample and evaluate probability density functions via neural networks. In this work we address two applications of them in the domain of neutrino physics: i) Perform likelihood-free inference of the measurement of neutrino oscillation parameters in Long Baseline neutrino experiments. A method adapted to physics parameter inference is developed and applied to the case of the disappearance of muon neutrino analysis at the T2K experiment. ii) The generation of accurate neutrino-nucleus cross-section models needed for neutrino oscillation experiments require simultaneously the description of many degrees of freedom and precise calculations to model nuclear responses. The detailed calculation of complete models makes the Monte Carlo generators slow and impractical. We present Exhaustive Neural Importance Sampling (ENIS), a method based on normalizing flows to find a suitable proposal density for rejection sampling automatically and efficiently, and discuss how this technique solves common issues of the rejection algorithm.

Primary authors: PINA-OTEY, Sebastian (IFAE/Grupo AIA); Prof. SÁNCHEZ, Federico (University of Geneva); Dr LUX, Thorsten (IFAE); Dr GAITAN, Vicens (Grupo AIA)

Presenter: PINA-OTEY, Sebastian (IFAE/Grupo AIA)

Session Classification: Day 2 Morning

Contribution ID: **36** Type: **Individual talk**

Graph Neural Networks for Reconstruction in Liquid Argon Time Projection Chambers

Tuesday, 14 July 2020 10:00 (25 minutes)

Graph neural networks (GNNs) are a category of neural networks which operate on graph-structured inputs, instead of the grid-structured inputs required by a CNN. Building on work developed for the HL-LHC for particle tracking with GNNs as part of the Exa.TrkX collaboration, this talk presents work to develop GNN-based techniques for hit-level reconstruction in Liquid Argon Time Projection Chambers (LArTPCs). A summary is provided of workflows to perform clustering and spacepoint deghosting in two and three dimensions, using simulations of both atmospheric and beam neutrino interactions, primarily utilising an attention message-passing GNN architecture. Preliminary results will be presented for the application of edge classification to group hits into clusters, and future plans for exploring a broader variety of GNN architectures will be discussed.

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

Presenter: Dr HEWES, Jeremy (University of Cincinnati)

Session Classification: Day 2 Morning

Contribution ID: **37** Type: **Individual talk**

GPU as a Service for Accelerating Machine Learning Applications in the Reconstruction Workflows of Neutrino Experiments

Wednesday, 22 July 2020 13:40 (25 minutes)

The employment of machine learning (ML) techniques has now become commonplace in the offline reconstruction workflows of modern neutrino experiments. Since such workflows are typically run on CPU-based high-througput computing (HTC) clusters with limited or no access to ML accelerators like GPU or FPGA coprocessors, the ML algorithms, for which CPUs are not the best suited platform, tend to dominate the total computational time of the workflows. In this talk we explore a computing model that provides GPUs as a Service (GPUaaS), where ML algorithms in offline neutrino reconstruction workflows running on typical HTC clusters can send inference requests to and receive the results from remote GPU-based inference servers running in the cloud, in a completely seamless fashion. We demonstrate a proof-of-principle using the full ProtoDUNE reconstruction chain, where we are able to acclerate the ML portion of the workflow by more than an order of magnitude, resulting in an overall 2-3x speed improvement. We also present scaling studies where we measure the performance as a function of the number of simultaneous clients.

Primary authors: HAWKS, Benjamin (Fermilab); HOLZMAN, Burt (Fermilab); PEDRO, Kevin (Fermilab); ACOSTA FLECHAS, Maria (Fermilab); WANG, Michael (Fermilab); TRAN, Nhan (Fermilab); YANG, Tingjun (Fermilab)

Presenter: YANG, Tingjun (Fermilab)

Session Classification: Day 4 Afternoon

Contribution ID: **39** Type: **Individual talk**

Inverse Beta Decay Reconstruction in Super-Kamiokande with CNNs

Friday, 24 July 2020 10:40 (25 minutes)

Inverse beta decay is the primary interaction mode for low energy electron anti-neutrinos, producing two signals in a water Cherenkov detector like Super-Kamiokande: a low energy positron and, ~200 μs later, a neutron capture on hydrogen producing a 2.2 MeV photon. These result in only ~10 of SK's 11,000+ photomultiplier tubes being hit by light, making them difficult to differentiate from radioactive background. If the two hit patterns are overlaid, however, the combined information could serve as input for a convolutional neural network. The initial investigations into a CNN IBD reconstruction tool for SK will be presented.

Primary author: GOLDSACK, Alexander (University of Oxford/Kavli IPMU)

Presenter: GOLDSACK, Alexander (University of Oxford/Kavli IPMU)

Session Classification: Day 5 Morning

Contribution ID: **41** Type: **A collaboration/project summary talk**

Machine Learning in DUNE

Session Classification: Day 4 Morning

Contribution ID: **42** Type: **A collaboration/project summary talk**

Scalable, Distributed Machine Learning

Machine learning in neutrino physics leverages many tools and techniques from the more mainstream areas of computer vision, but also brings new and interesting challenges. Notably, neutrino experiments have large images, typically with very high resolution, and often sparse or irregular data. In this talk I'll present several techniques that are successfully shown to accelerate machine learning for neutrino physics, including distributed learning, sparse and parallel IO, and tips for running on large scale systems.

Presenter: ADAMS, Corey (Argonne National Laboratory)

Session Classification: Day 4 Afternoon

Contribution ID: **43** Type: **not specified**

White paper discussion

Friday, 24 July 2020 14:30 (20 minutes)

Presenter: AURISANO, Adam (University of Cincinnati)

Session Classification: Day 5 Afternoon

Contribution ID: **44** Type: **not specified**

Closing

Friday, 24 July 2020 14:50 (15 minutes)

Presenter: TERAO, Kazuhiro (SLAC)

Session Classification: Day 5 Afternoon

Contribution ID: **45** Type: **not specified**

Welcome: High Energy Physics and Machine Learning

Friday, 10 July 2020 10:10 (15 minutes)

Presenter: Dr COOKE, Michael (U.S. Department of Energy)

Session Classification: Day 1 Morning

Contribution ID: **46** Type: **not specified**

White paper introduction

Friday, 10 July 2020 10:25 (20 minutes)

Presenter: AURISANO, Adam (University of Cincinnati)

Session Classification: Day 1 Morning

Contribution ID: **47** Type: **Individual talk**

Uncertainty estimation for Deep Learning in Neutrino Physics

Tuesday, 21 July 2020 11:55 (25 minutes)

Deep neural networks are becoming increasingly pervasive in science and engineering applications. These networks are often treated as high-fidelity models with accurate predictive powers by end users. However, even predictions from a trained neural network may contain significant errors and uncertainties due to bias, noise and complexity of the data; the volume of the training data; the nature of the error minimum chosen during optimization; and the hyperparameters and network structure, etc.

In safety critical applications, such as autonomous vehicles, particle physics, etc ignoring this uncertainty may have grave consequences. In such cases along with accurate predictions, users require reliable estimates of uncertainties in model predictions. In this context, Bayesian Neural Networks (BNNs) are opportune as they amalgamate the predictive
ability of neural networks with the uncertainty quantification due to the Bayesian formalism. In this investigation, we apply Bayesian Neural Networks to a variety of problems germane to Neutrino physics. The accuracy and coverage of Bayesian Neural Networks is reported and analyzed across this cross section of problems. Additionally, we compare and contrast BNNs to other approaches such as Model Ensembling to analyze their efficacy at quantifying uncertainties.

Primary author: Dr MISHRA, Aashwin (SLAC)

Presenter: Dr MISHRA, Aashwin (SLAC)

Session Classification: Day 3 Morning

Contribution ID: **48** Type: **not specified**

Introduction

Friday, 10 July 2020 10:00 (10 minutes)

Presenters: AURISANO, Adam (University of Cincinnati); ADAMS, Corey (Argonne National Laboratory); BIAN, Jianming (University of California, Irvine); TERAO, Kazuhiro (SLAC); DEL TUTTO, Marco (Fermilab); PROUSE, Nick (TRIUMF); DE PERIO, Patrick (TRIUMF); WONGJIRAD, Taritree (Tufts University)

Session Classification: Day 1 Morning

Contribution ID: **49** Type: **A collaboration/project summary talk**

Scalable, Distributed Machine Learning¶

Wednesday, 22 July 2020 14:05 (40 minutes)

Machine learning in neutrino physics leverages many tools and techniques from the more mainstream areas of computer vision, but also brings new and interesting challenges. Notably, neutrino experiments have large images, typically with very high resolution, and often sparse or irregular data. In this talk I'll present several techniques that are successfully shown to accelerate machine learning for neutrino physics, including distributed learning, sparse and parallel IO, and tips for running on large scale systems.

Primary author: ADAMS, Corey (Argonne National Laboratory)

Presenter: ADAMS, Corey (Argonne National Laboratory)

Session Classification: Day 4 Afternoon

Contribution ID: **50** Type: **A collaboration/project summary talk**

Deep learning in DUNE

Wednesday, 22 July 2020 10:00 (40 minutes)

The Deep Underground Neutrino Experiment (DUNE) is a next-generation neutrino oscillation experiment that aims to measure CP-violation in the neutrino sector as part of a wider physics program. A deep learning approach based on a convolutional neural network has been developed to provide highly efficient and pure selections of electron neutrino and muon neutrino charged-current interactions. The electron neutrino (antineutrino) selection efficiency peaks at 90% (94%) and exceeds 85% (90%) for reconstructed neutrino energies between 2-5 GeV. The muon neutrino (antineutrino) event selection is found to have a maximum efficiency of 96% (97%) and exceeds 90% (95%) efficiency for reconstructed neutrino energies above 2 GeV. When considering all electron neutrino and antineutrino interactions as signal, a selection purity of 90% is achieved. These event selections are critical to maximize the sensitivity of the experiment to CP-violating effects. In addition to the above, this talk will also discuss other deep learning studies in DUNE.

Primary author: ALONSO MONSALVE, Saul (CERN)

Presenter: ALONSO MONSALVE, Saul (CERN)

Session Classification: Day 4 Morning