Fermilab

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NPML 2025 In Review

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NPC Journal Club

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NPML 2025

What is NPML?

- Neutrino Physics and Machine Learning
- How can we apply new and emerging machining learning technologies to neutrino physics?
- Newer conference (started 2020, first in-person 2023)
- NPML 2025 was in Tokyo, Japan
- NPML 2026 is planned to be at UC Irvine

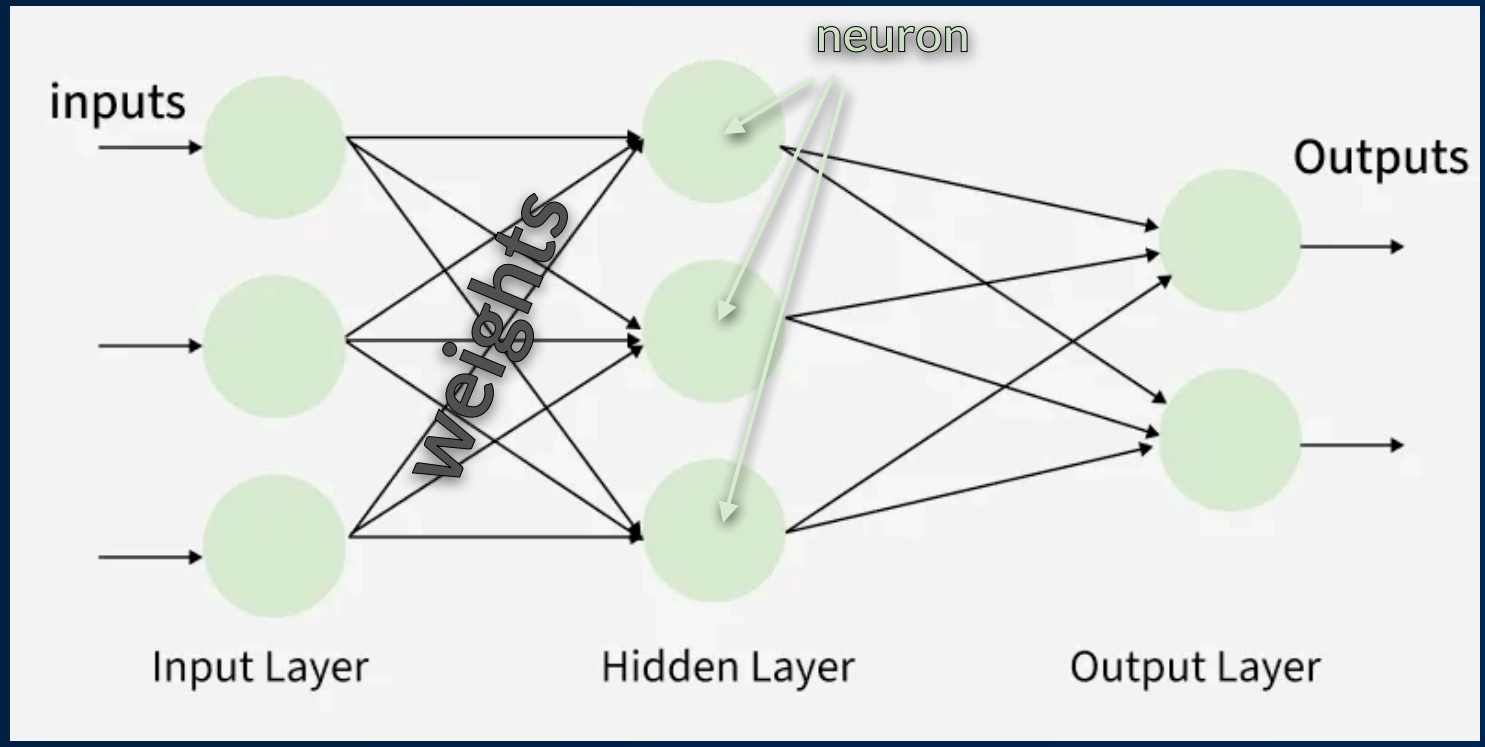
NPML 2025

High-Level Overview

- Most talks were about how current neutrino experiments were using ML tools on their experiments
  - Track reconstruction, PID, etc…
- Other topics included anomaly detection, detector modeling, interaction modeling, and more
- Start with some general ML ideas, and then see how they were applied in some of the NPML reports
- I'll try to hit the highlights, but my hope is this leads more to a discussion of how we can best use ML in neutrino physics
- If these topics are of interest, consider signing up for the NPML mailing list: https://docs.google.com/forms/d/e/1FAIpQLSfmgVt38Cdul3g0tL6tkr7TNy2Y-Sv6HPw_dbaPANfq6E6HTw/viewform

Machine Learning Basics

Multilayer Perceptron



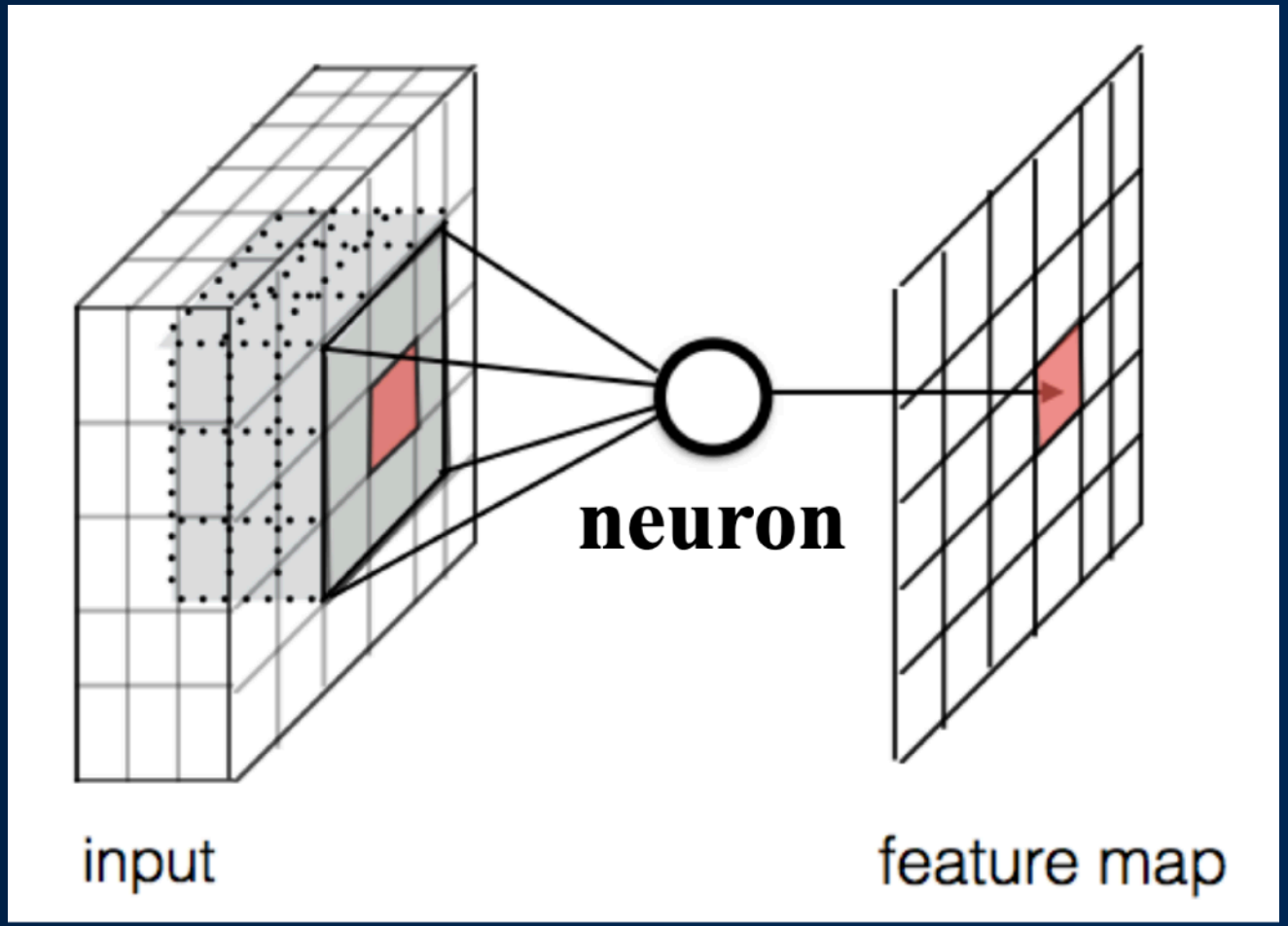
- Each layer takes a vector of inputs (features), and linearly* maps them to new values
  - New values are then plugged into an activation function to obtain neuron value
- Can chain multiple layers together to analyze complex features

*technically affine

Machine Learning Basics

Convolutional Neural Networks

- Convolutional Neural Networks (CNN) are helpful for image analysis
- If each pixel were a feature, a MLP would need many, many weights
- Instead pass each neuron only local information in some neighborhood of a pixel
- Multiplying features by weights ⇒ convolving pixel values with a kernel



Machine Learning Basics

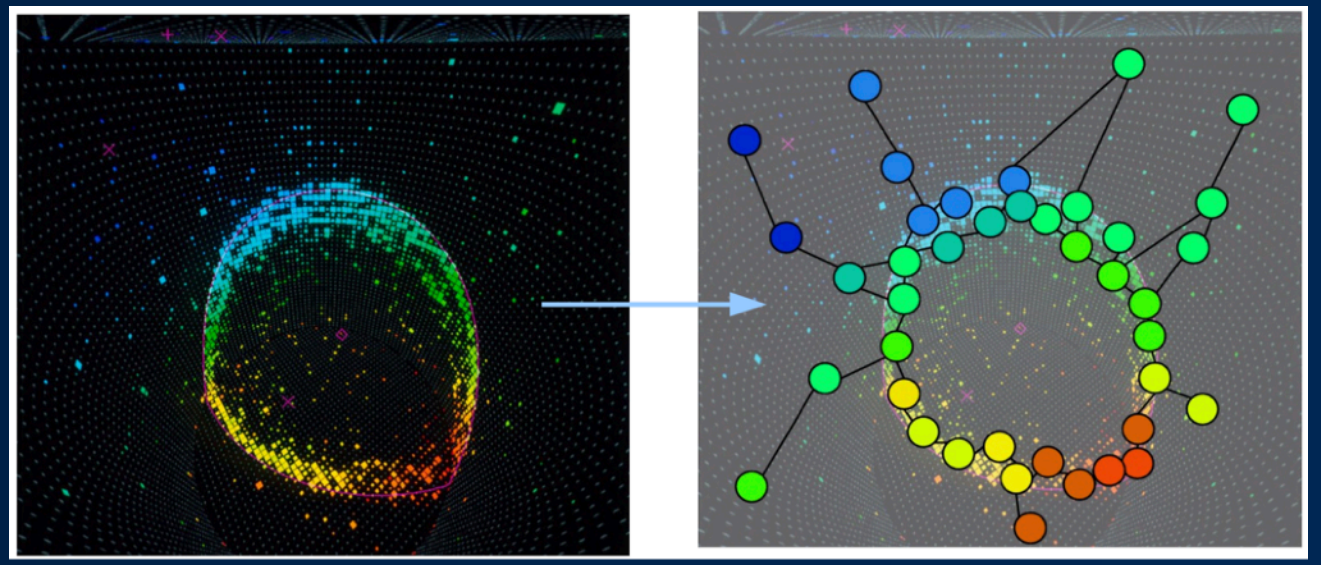
Graph Neural Network

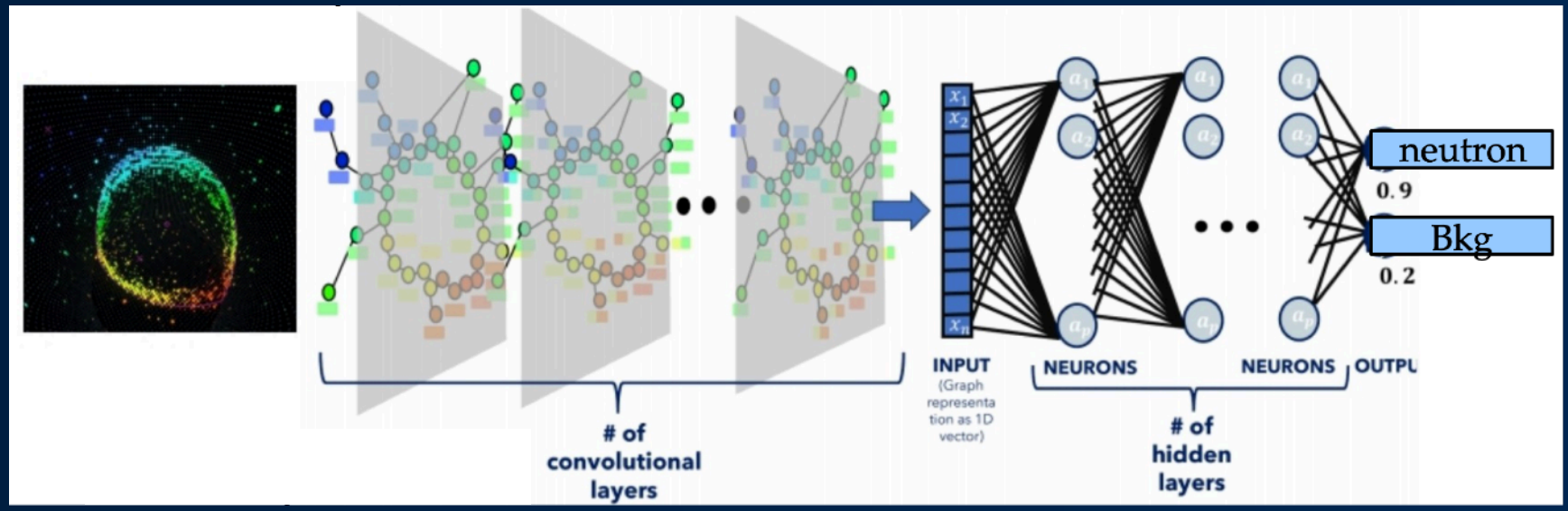
- Instead of an image (ie dense matrix of data) consider wanting to draw predictions from a **graph**
- Each node has features, each layer updates based on the edges (which nodes are connected)
- Can extract node, edge, or global level features

Reconstruction in Super & Hyper-K

Talk by Benjamin Quilain

- In Super/Hyper-K each PMT has features (charge, time, position, etc)
- Make PMTs into nodes
- Use GNNs to map PMT graphs into event classifications

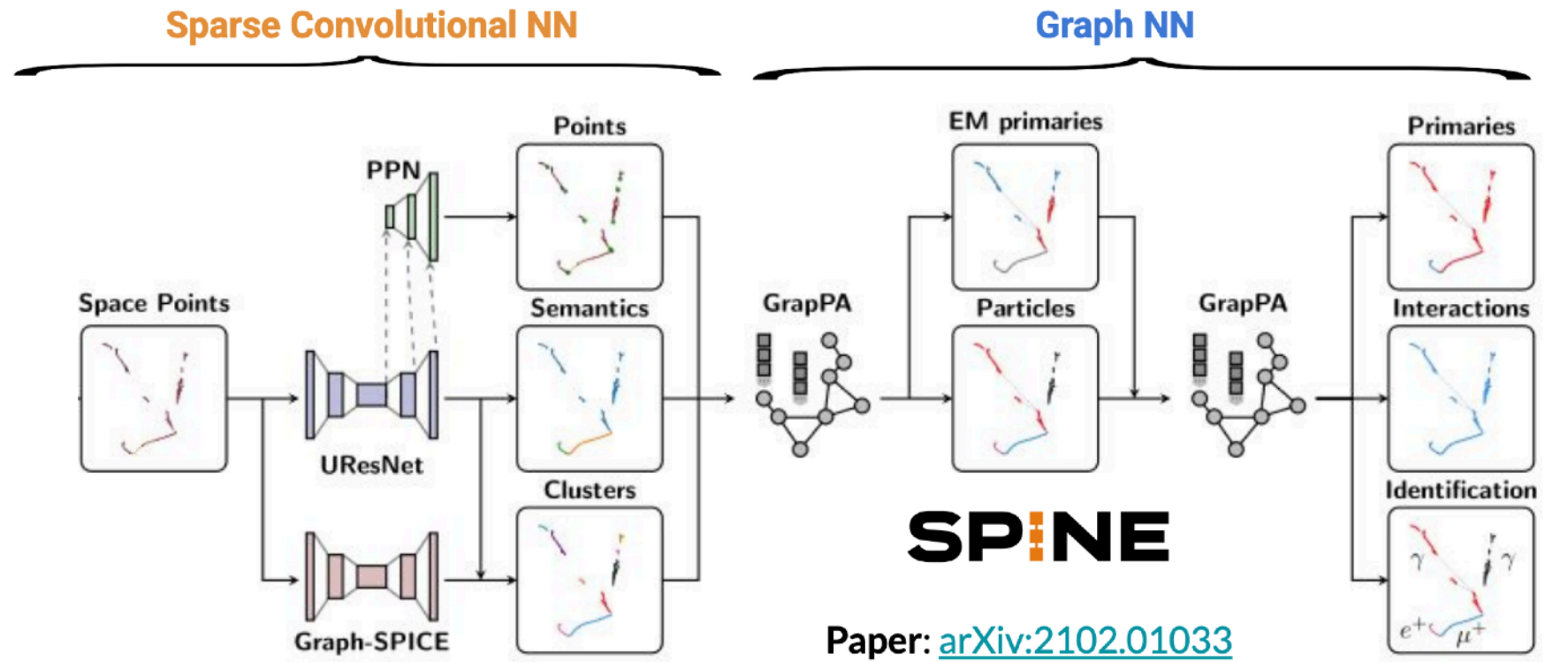




Deep Neural Network Cascade for the Deep Underground Neutrino Experiment

Talk by François Drielsma

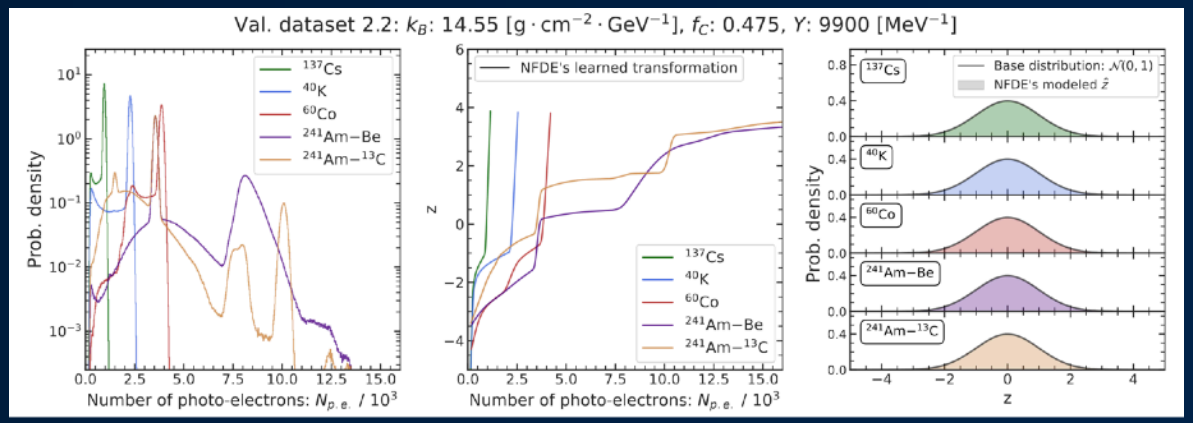
- Scalable Particle Imaging with Neural Embeddings (SPINE)
- CNNs for image-level features
- GNNs for interaction-level features

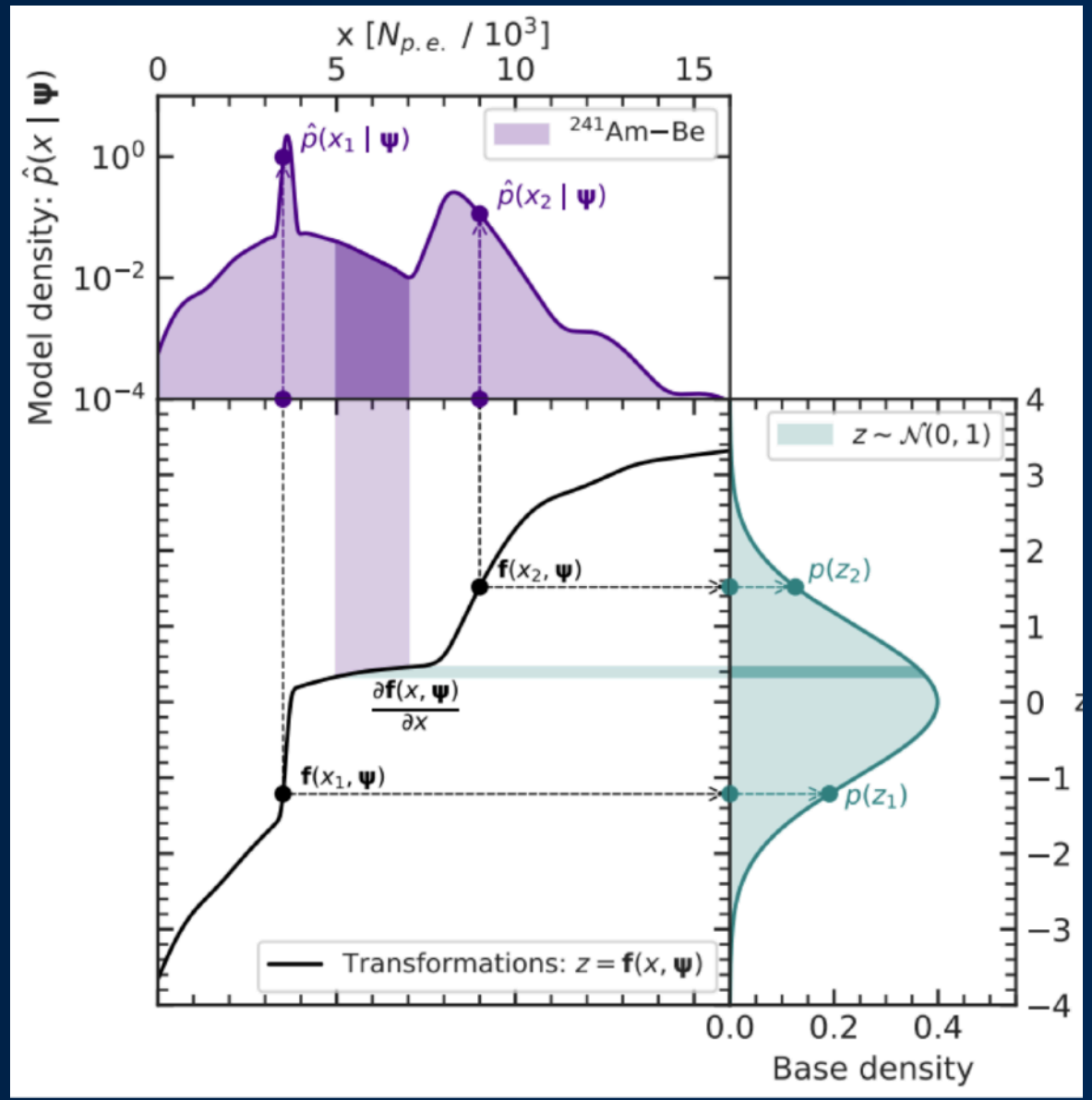


Simulation-based Inference for Precision Neutrino Physics through Neural Monte Carlo Tuning

Talk by Andrea Sefafini

- On JUNO they are using Normalizing Flows-based Density Estimators (NFDE) to generate MC samples for different physical parameters
- Train a model to learn how to go from a physical distribution to a Gaussian
- Throw on the Gaussians to produce MC distributions

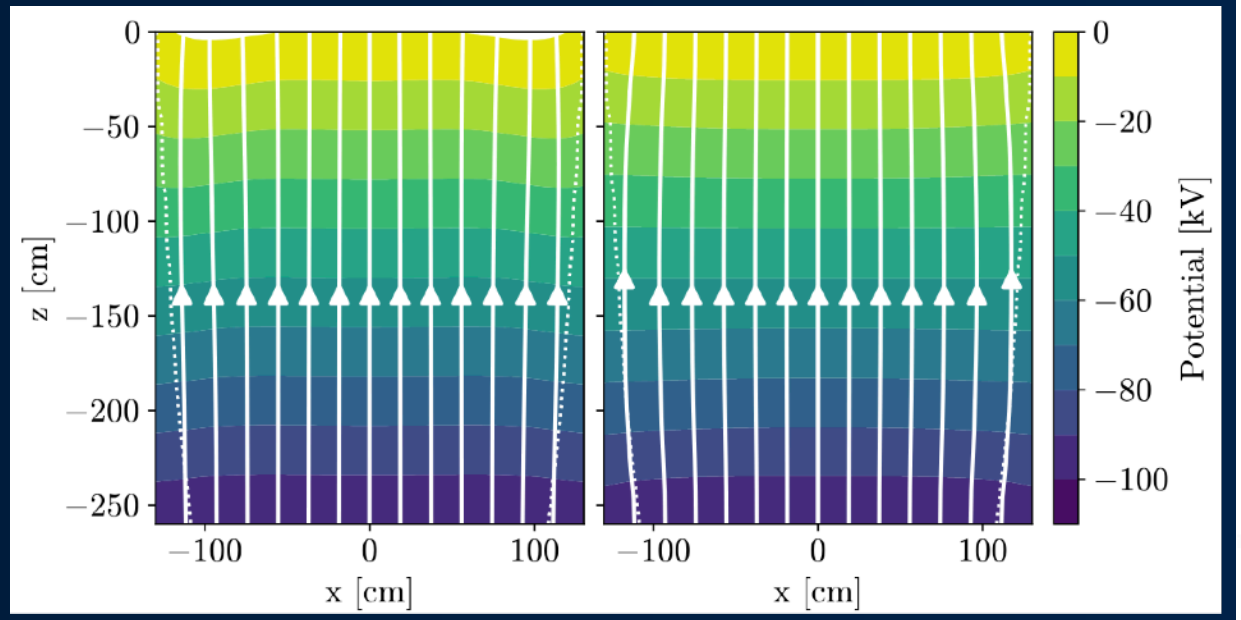


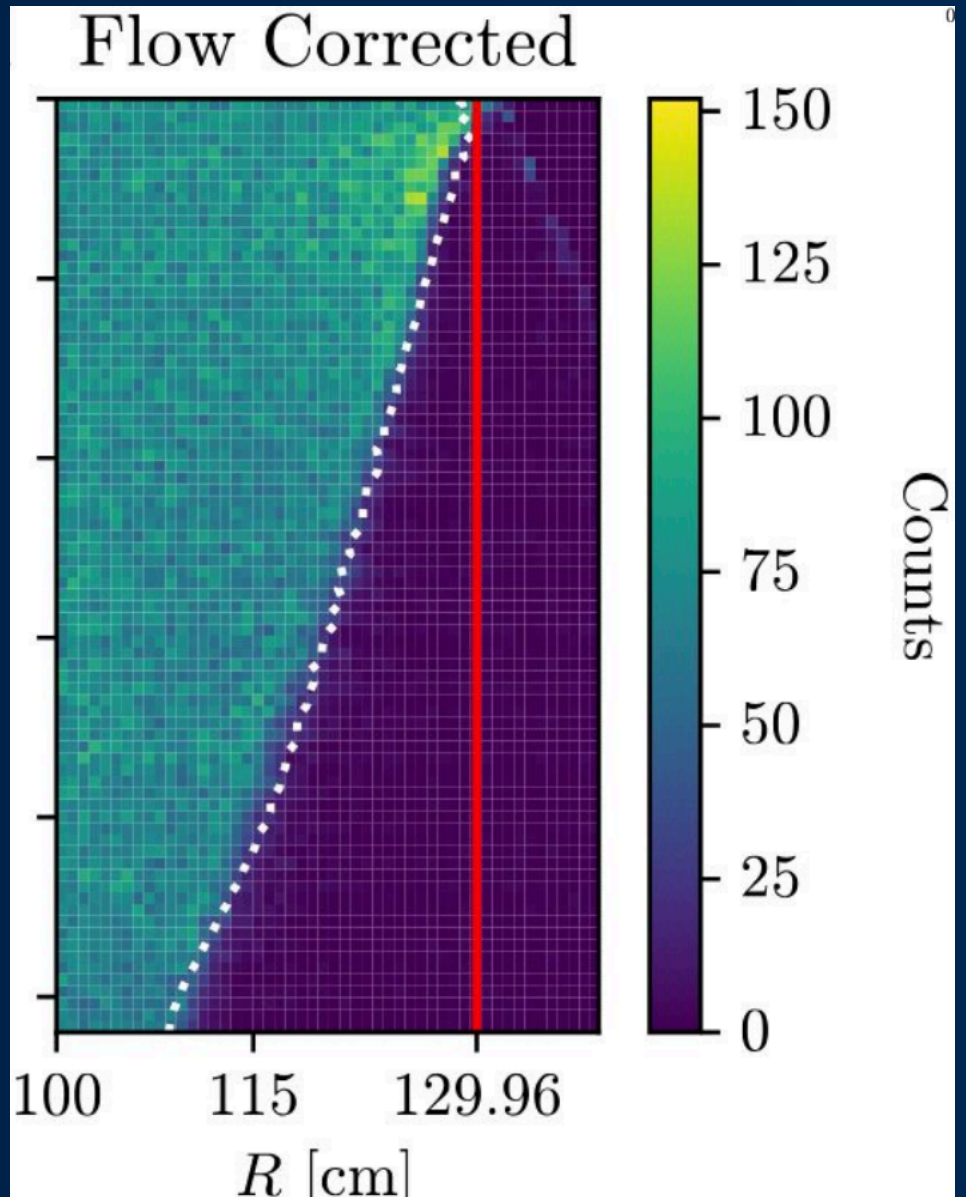


Determining a TPC Electric Field using Physics-Informed Continuous Normalizing Flows

Talk by Ivy Li

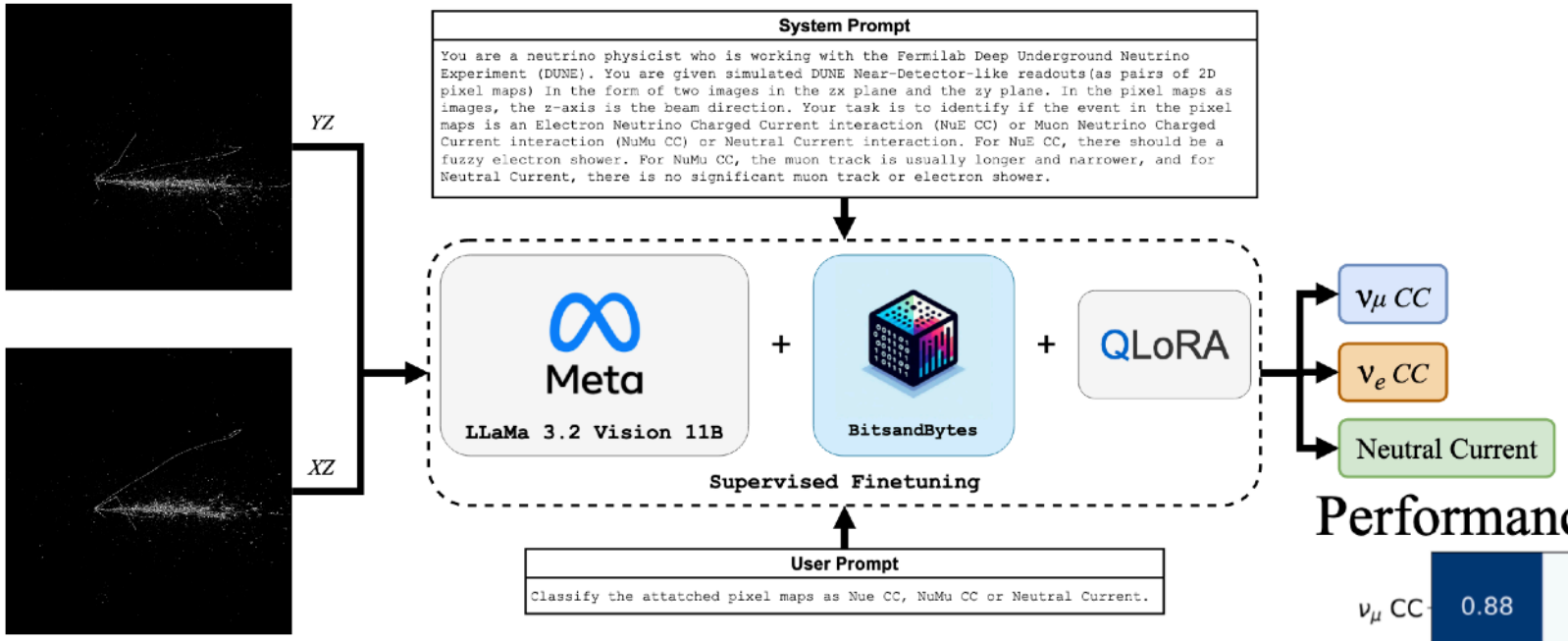
- Model electric field inside XENONnT with normalizing flows
- Physics-informed continuous normalizing flow to model electron movement





AI/ML at DUNE

Talk by Jianming Bian



- Use LLMs to identify neutrino interactions?
- Ask the LLM in plain English to interpret the event from 2D LArTPC images

Performance

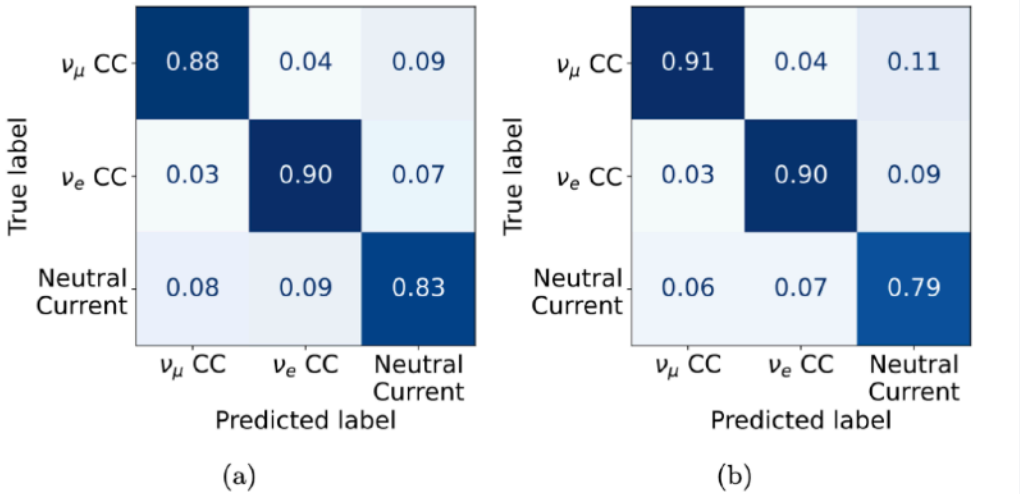


Figure 5: Finetuned LLaMa 3.2 Vision's (a) recall matrix (truth normalized) and (b) precision matrix (prediction normalized).

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Discussion Time