Machine Learning Approaches to Particle Identification in the DUNE Far Detector

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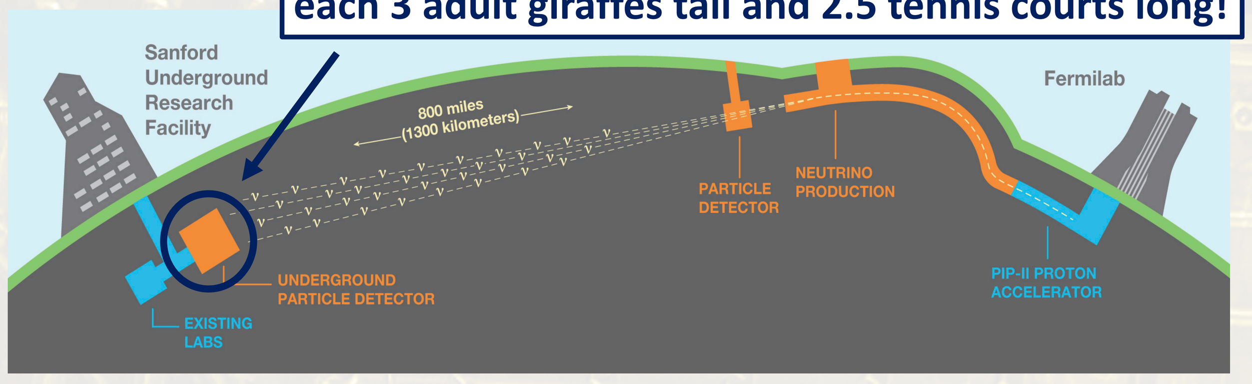
1 Overview

1) Developments of the **Pandora reconstruction software** (3) should be motivated by **analyses**
2) We target the search for **CP-violation with the DUNE far detectors** (2)
3) Here one identifies **charged current (CC) ν_e/ν_μ** interactions
4) In the **Pandora-based analysis**, (4) the success of this relies on:
   a) a performant reconstruction software
   b) excellent particle identification (PID)
5) Here we focus on a machine learning approach to particle identification (5)

2 DUNE and its Far Detectors [1]

Four 10kt fiducial volume far detector modules, **each 3 adult giraffes tall and 2.5 tennis courts long!**

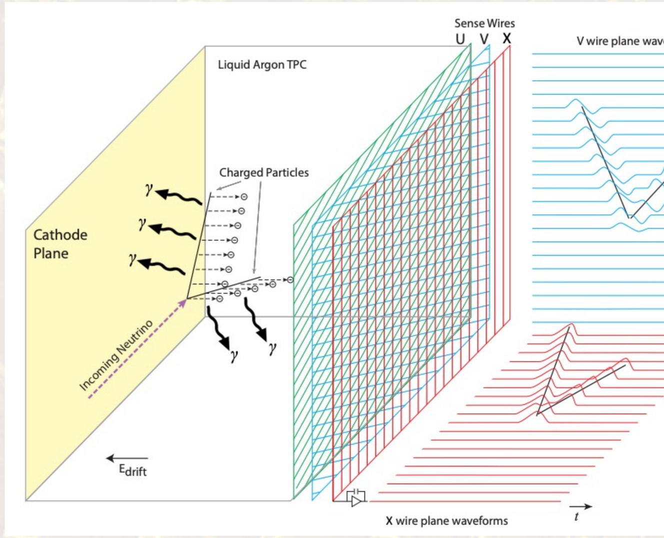


DUNE primarily aims to:

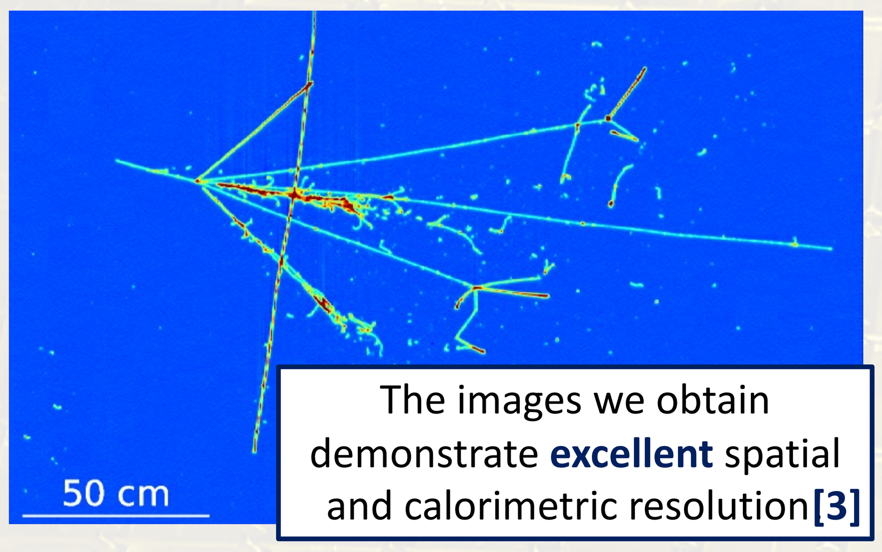
- Make **precise** neutrino oscillation measurements
- Search for **BSM** physics (e.g. proton decay)
- Study **low energy** neutrinos (e.g. supernova neutrinos)

Three modules will be Liquid-Argon Time-Projection Chambers:

- Neutrinos interact with **LAr nuclei**
- Light collected by **photon detection system,** providing timing information
- Outgoing charged particles **ionise the LAr nuclei**
- Ionisation electrons drifted to **readout planes by an applied electric field**



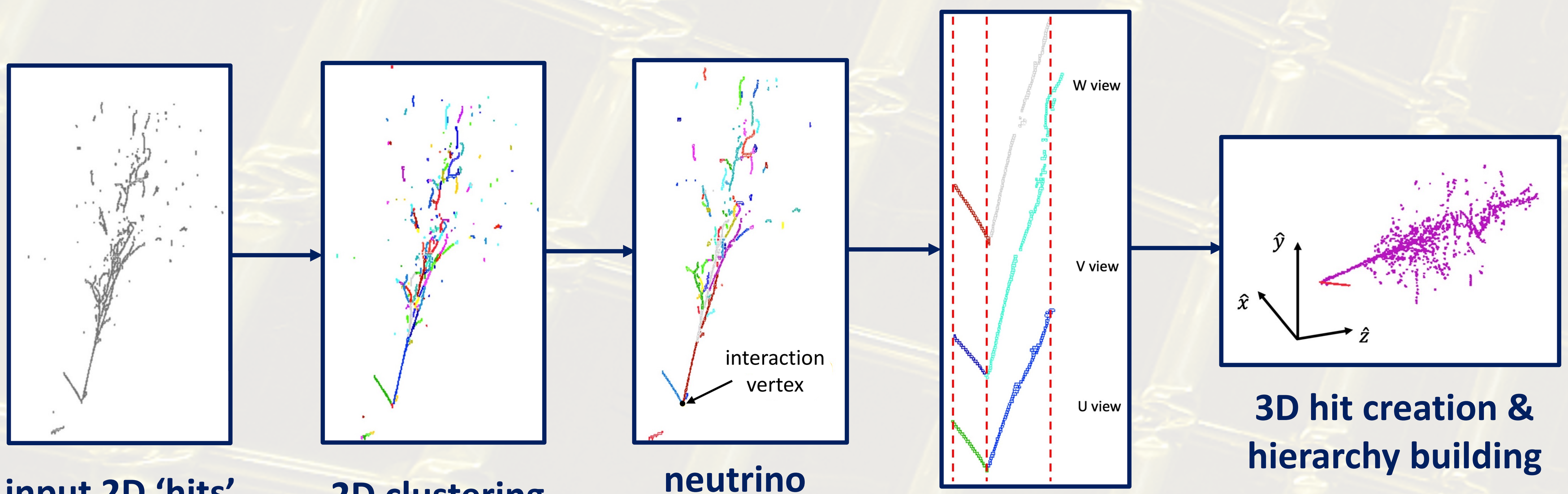
[2]



The images we obtain demonstrate **excellent** spatial and calorimetric resolution[3]

3 Pandora – the hope left in the jar [4,5]

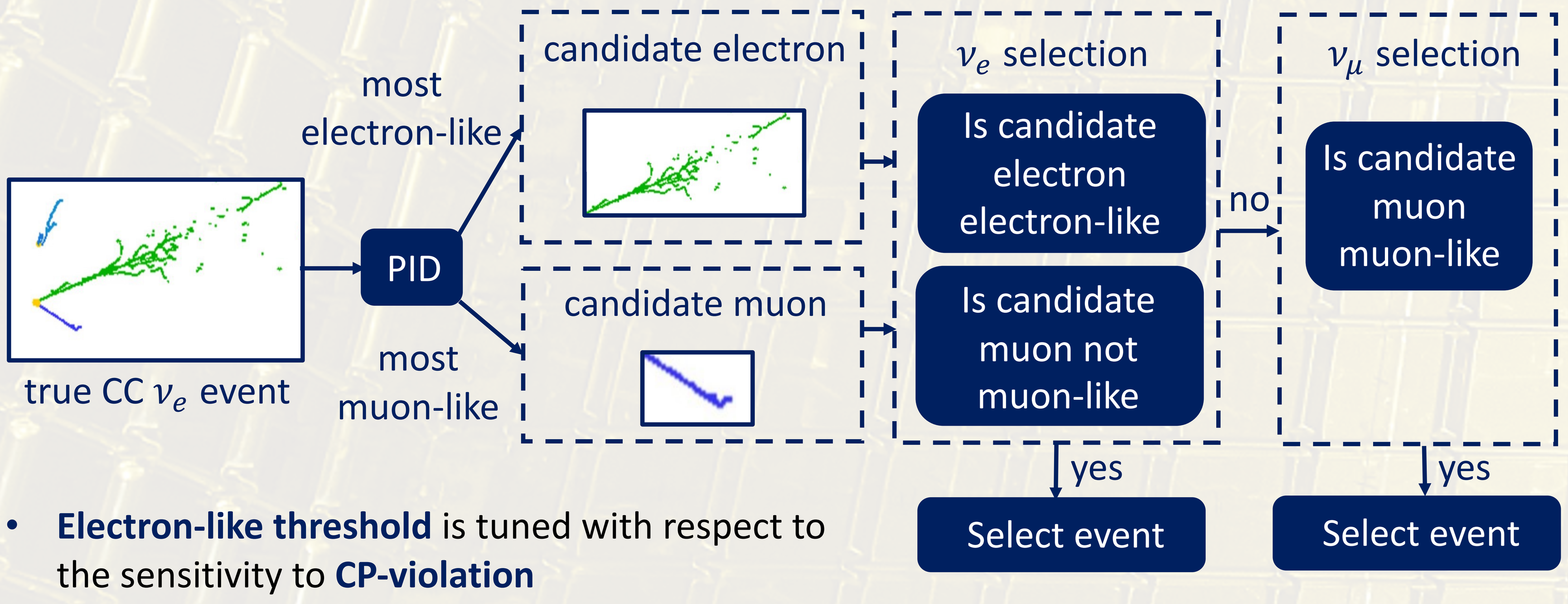
- Pandora is a **pattern recognition software**, used to reconstruct neutrino interactions
- The detail of the fine-grain images (see (2)) presents a huge reconstruction challenge
- Pandora overcomes this with a **'multi-algorithm approach',** where the reconstruction is split into stages composed of many 'hand engineered' and machine learning algorithms



input 2D 'hits' → **2D clustering** → **neutrino vertexing** → **2D → 3D matching** → **3D hit creation & hierarchy building**

4 The Pandora-based CC ν_e/ν_μ selection [6]

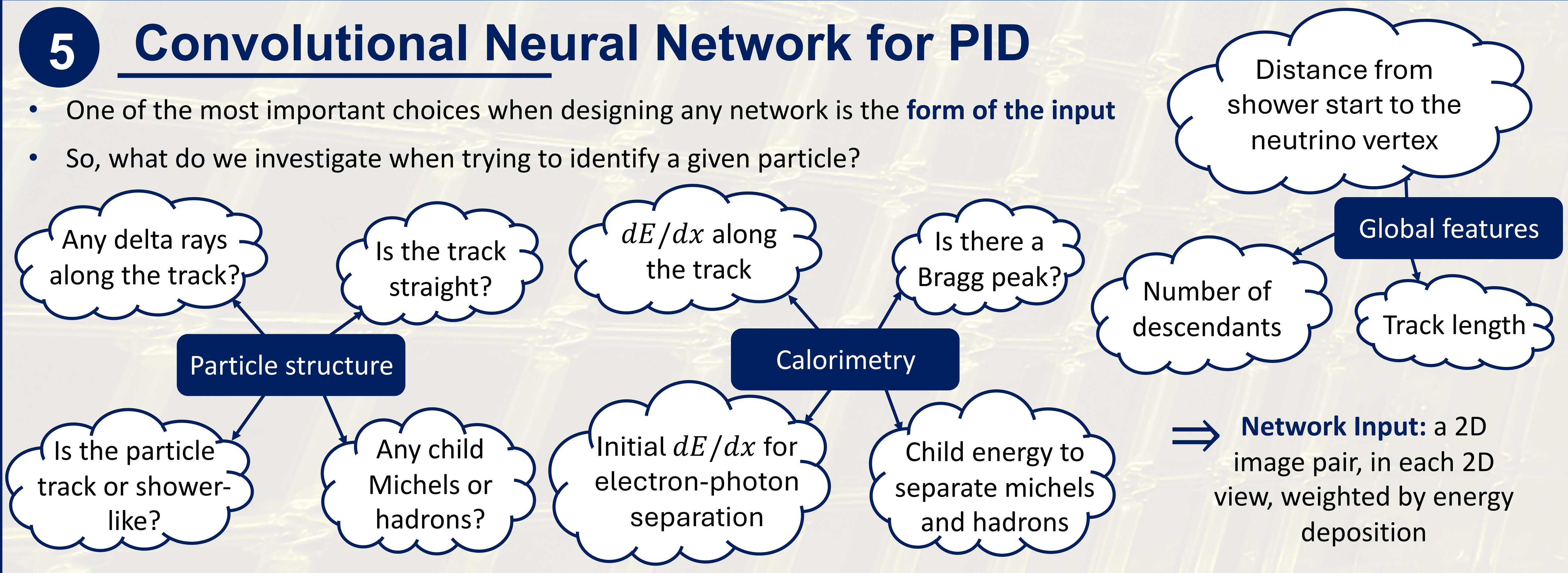
- Events are selected based on the assumed identity of the **leading lepton (if it exists)**



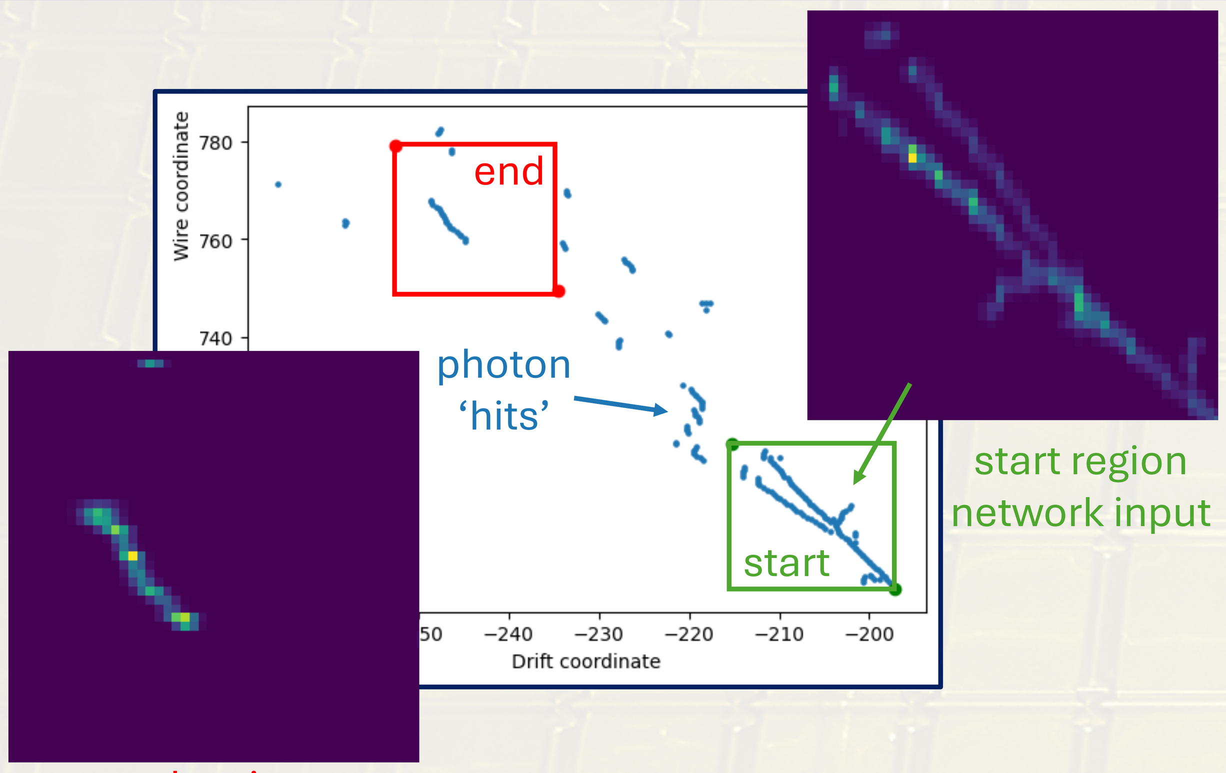
- **Electron-like threshold** is tuned with respect to the sensitivity to **CP-violation**
- **Muon-like threshold** is tuned with respect to the product of the **CC ν_μ selection efficiency and purity**

5 Convolutional Neural Network for PID

- One of the most important choices when designing any network is the **form of the input**
- So, what do we investigate when trying to identify a given particle?

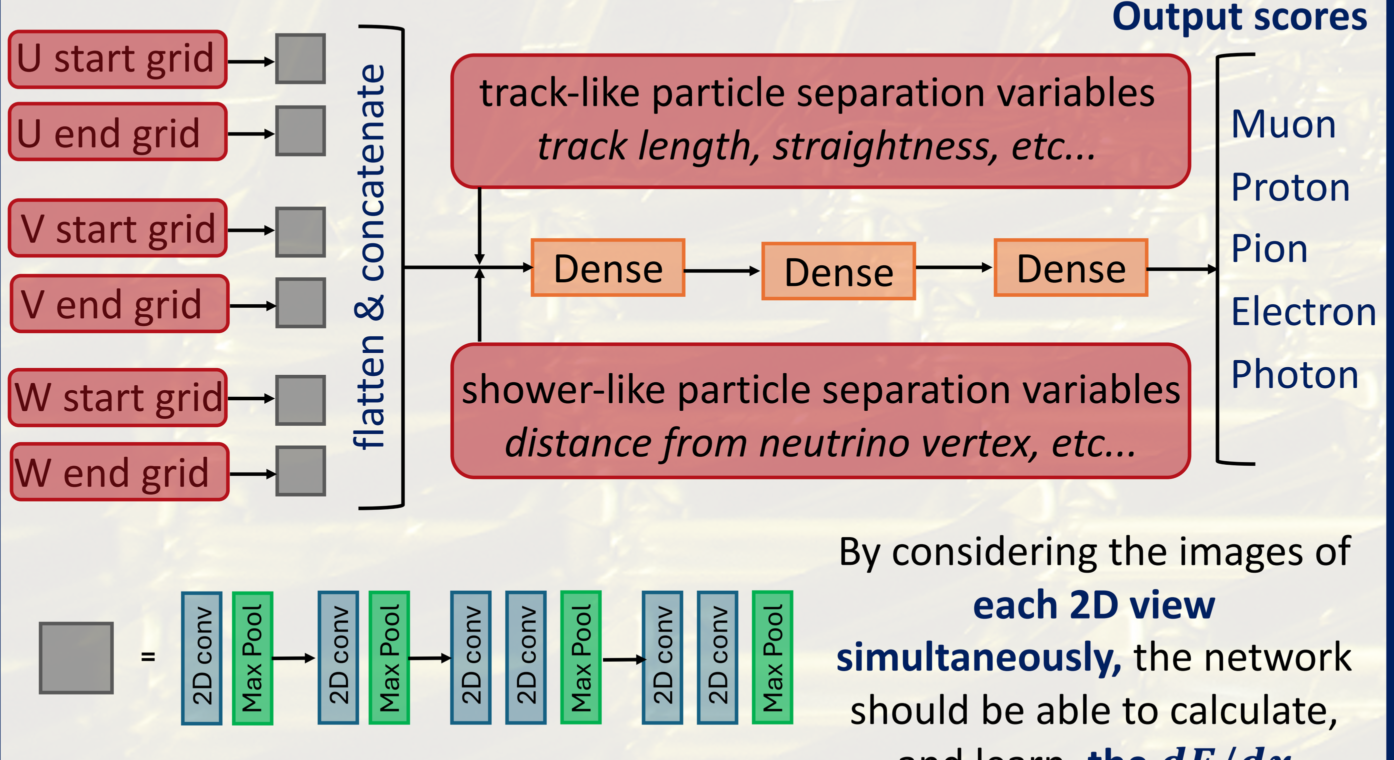


⇒ **Network Input:** a 2D image pair, in each 2D view, weighted by energy deposition



6 Network Architecture

- Architecture is a composition of **2D convolution** and **max pooling layers**
- Output particle type probability scores sum to **unity**

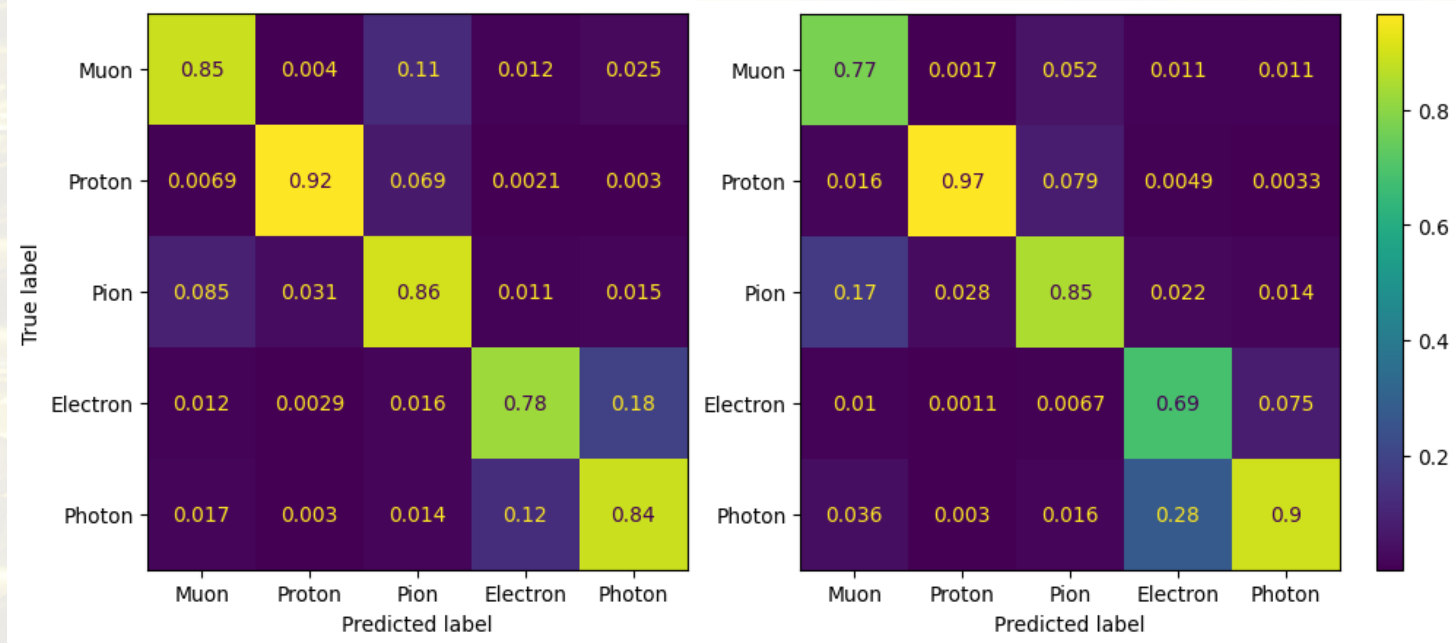


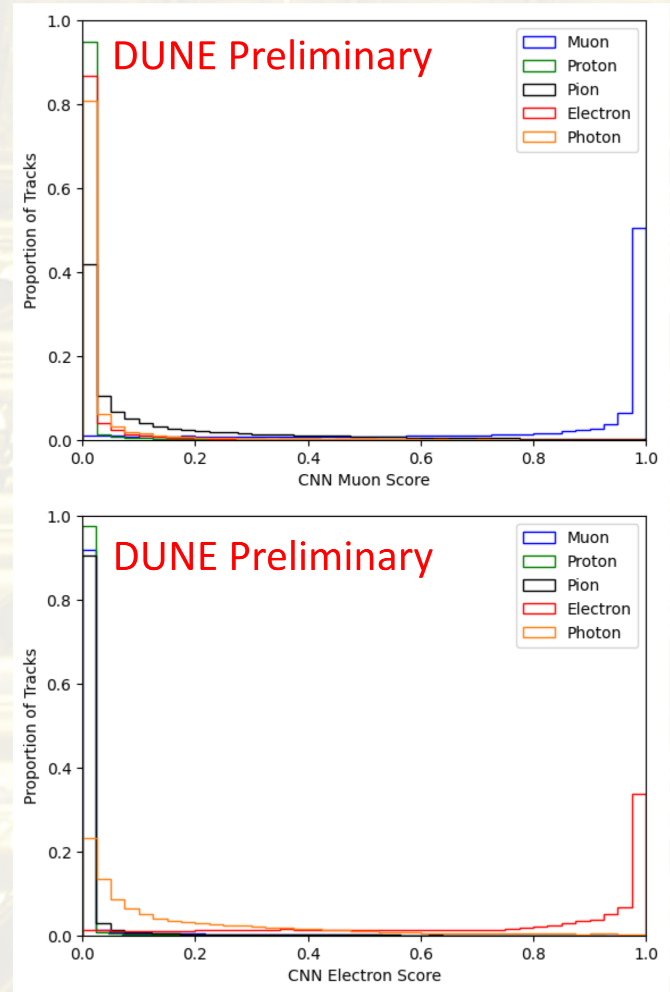
By considering the images of **each 2D view simultaneously,** the network should be able to calculate, and learn, **the dE/dx**

7 Results

- The convolution neural network approach achieves **good particle separation**
- As expected, main confusion between π/μ and e/γ

Efficiency normalised (read horizontally) **Purity normalised (read vertically)**





DUNE Preliminary	Selection Efficiency	Selection Purity
ν_e Selection	67.7%	72.7%
ν_μ Selection	92.8%	93.2%

- The ν_e **selection** is believed to be limited by the **reconstruction of electron** showers, particularly their **contamination and incomplete growth**
- The ν_μ **selection** is believed to be limited by π/μ **confusion**

8 What's next?

- The presented analysis has **directly motivated** several areas of ongoing developments to the Pandora reconstruction, most of which focus on the **reconstruction of electrons and photons**
- The use of **innovative machine learning** in the multi-algorithm approach is being investigated and is found to be performant

References

[1] DUNE Collaboration. (2020) JINST 15(08):08008
[2] DUNE Collaboration. (2020) JINST 15(08):08010
[3] DUNE Collaboration. (2020) JINST 15(12):12004
[4] MicroBooNE Collaboration. (2018) Eur Phys J C 78(1):82
[5] DUNE Collaboration. (2023) Eur Phys J C 83(7):618
[6] Isobel Mawby. (2023) FERMILAB-THESIS-2023-11