Machine Learning Approaches for ALERT Track matching

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ALERT Experiment Setup

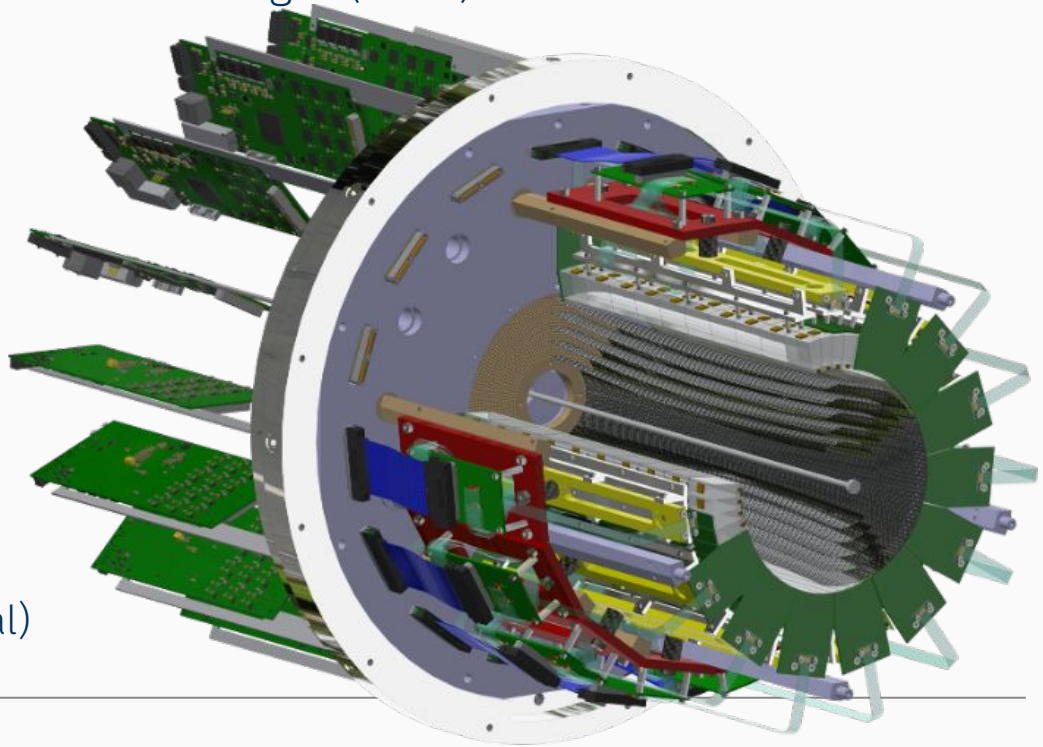
- ALERT is composed of two sub-detectors:
  - A Hyperbolic Drift Chamber (AHDC) and A Time of Flight (ATOF)

ATOF

- Time of flight: used for Particle Identification
- Small barrel of segmented scintillators
- The TOF measurement is degenerate for ^{2}H and ^{4}He, but dE/dx can distinguish the two nuclei bands

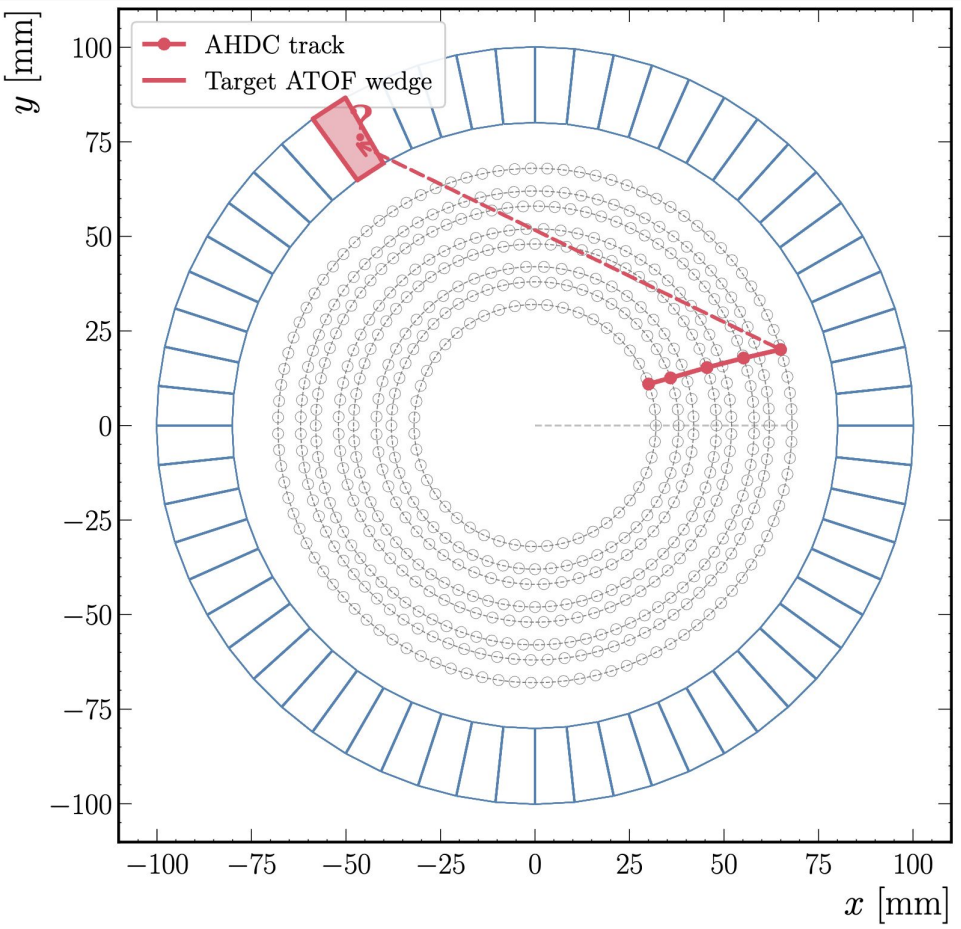
AHDC

- Aluminum wire: 2 mm apart
- 20-degree stereo angle (hyperbolic shape)
- 5 superlayers, each composed of 2 layers
- 576 signal wires (6 ground wires of each signal)



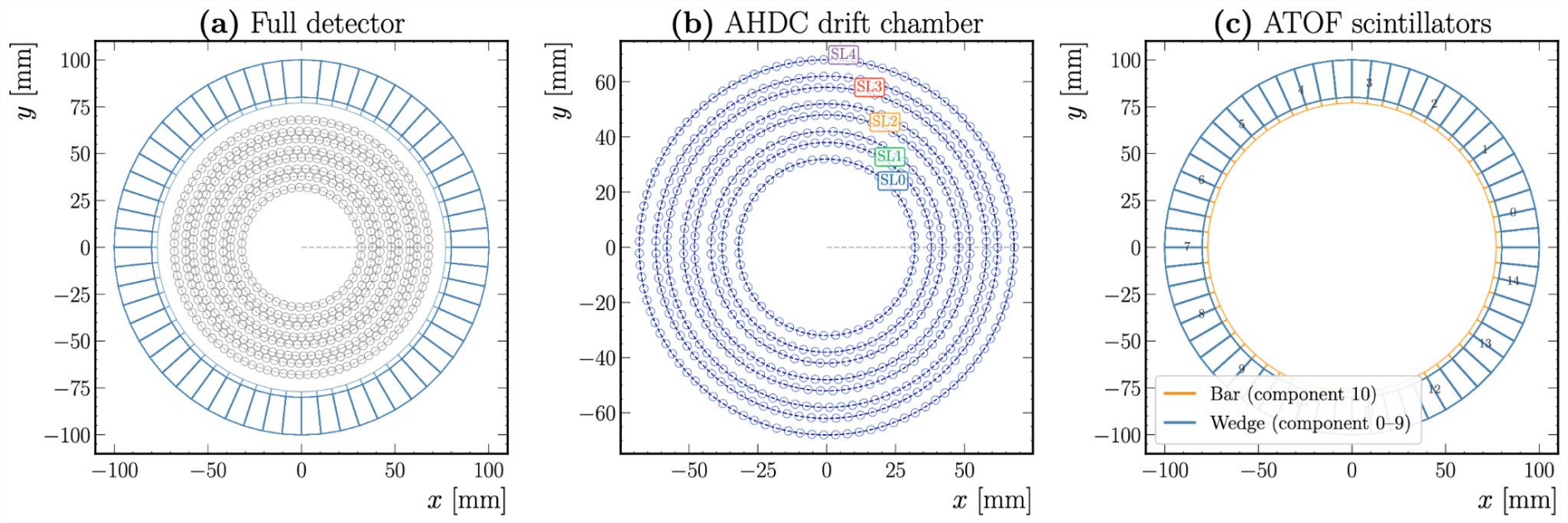
Introduction

- **Problem:**
  - Given a charged particle track reconstructed in the AHDC, predict which ATOF scintillator it will hit
- ATOF Address = 3 labels:
  - Sector (0–14): azimuthal φ
  - Layer (0–3): quarter within sector
  - Wedge (0–9): longitudinal z slice
  - Total: 600 possible paddle IDs
- Goal: with an AI, predict which wedge should be hit based on the inter-clusters:
  - Inputs: 5 of 2-D points (x, y)
  - Output: sector, layer, wedge



Detector Geometry

- Use information from the AHDC (one point per superlayer) to predict the wedge



Model Architecture

Shared experts

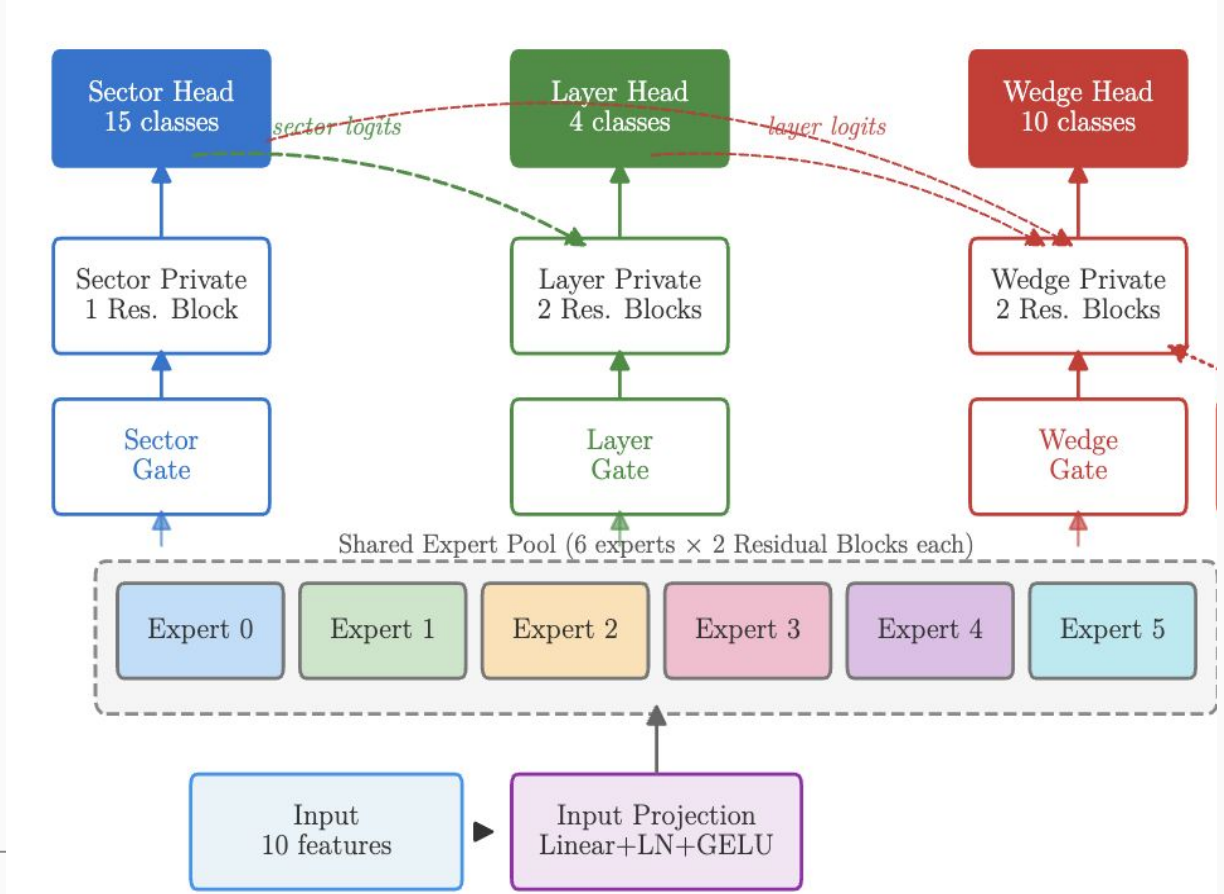
- 6 expert networks, each with 2 residual blocks (Linear+ LayerNorm+ReLU+Dropout)

Per-task gating

- Each task learns a softmax weighting over all experts, enabling task specialization

Cascaded conditioning

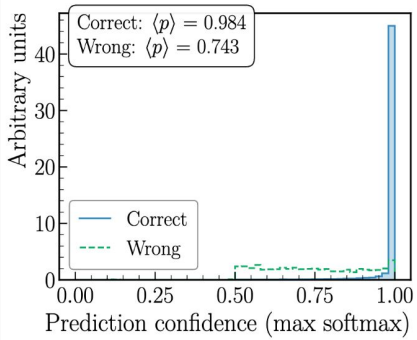
- Layer head receives sector logits, wedge head receives both sector and layer logits

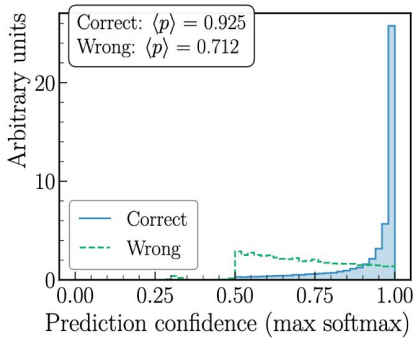


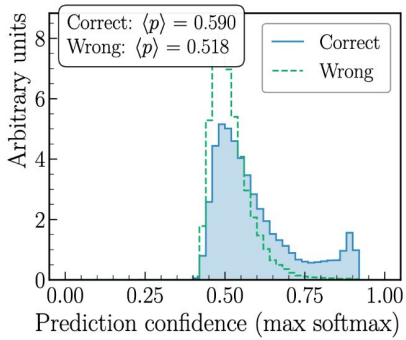
Training pipeline

Data

- From GEMC simulation
- 5M events with only ATOF hits
- Split: 70/15/15 train/val/test
- Batch size: 4096



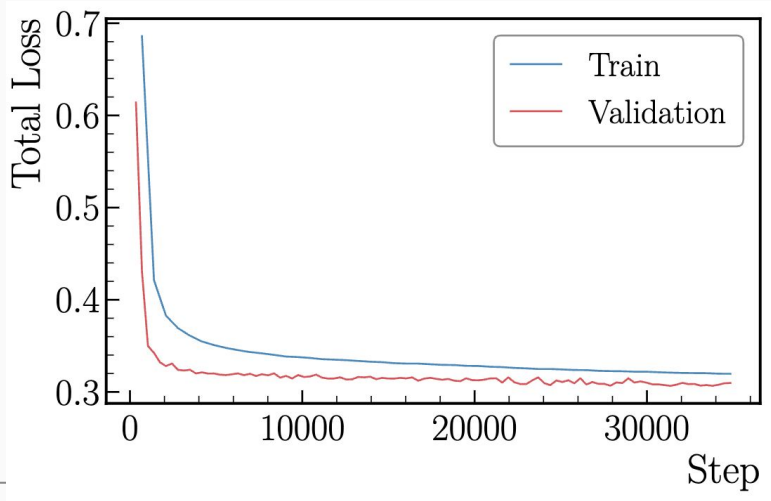




Loss Function

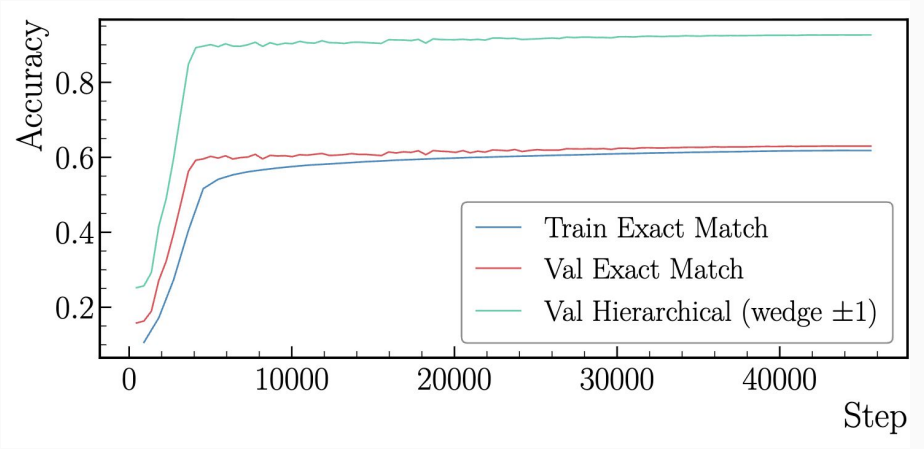
- Sector: Cross-Entropy
- Layer: Cross-Entropy
- Wedge: Focal loss (γ=2.0)

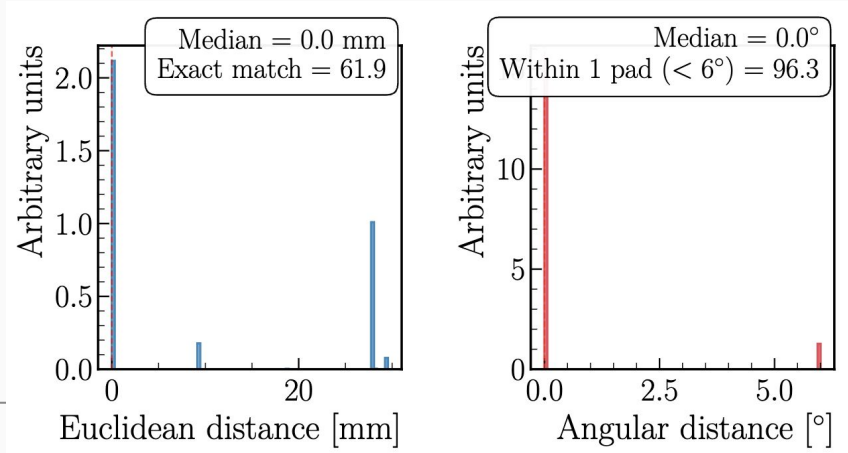
$$\mathcal{L} = w_s \mathcal{L}_{\text{sector}} + w_l \mathcal{L}_{\text{layer}} + w_w \mathcal{L}_{\text{wedge}}$$



Evaluation on Simulation

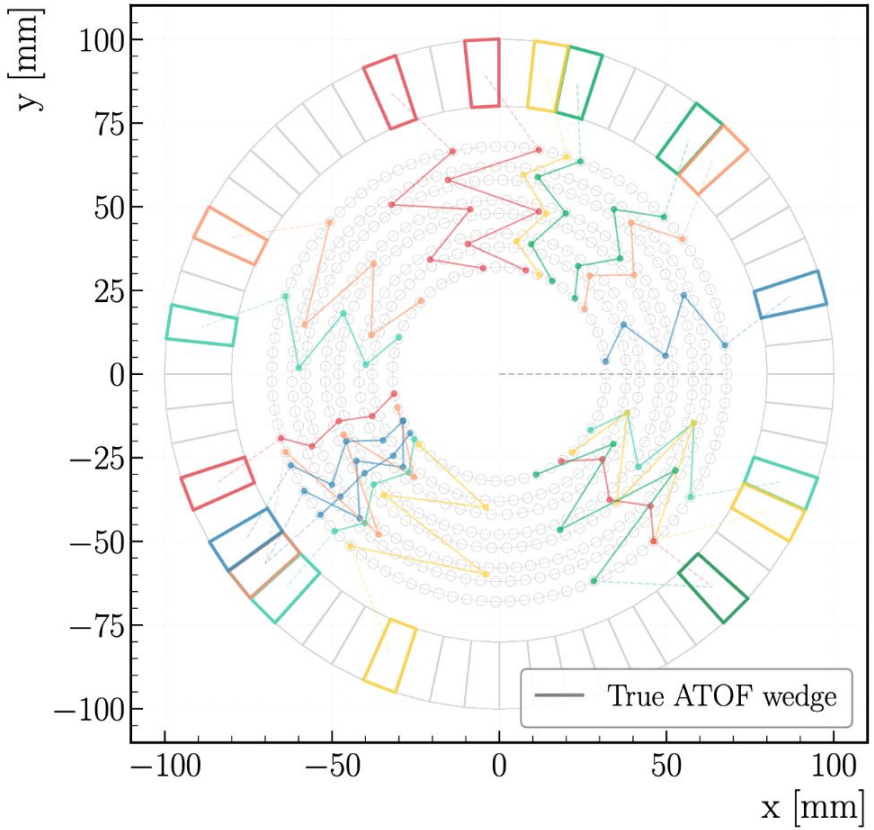
- Monitor the accuracy: how often the model predicts the good sector, layer, and wedge
- Accuracy off by one: how often the model predicts the correct sector, layer but the wedge is the correct one or off by one.
- The distance: the x,y,z distance between the center of the predicted wedge and the correct one.



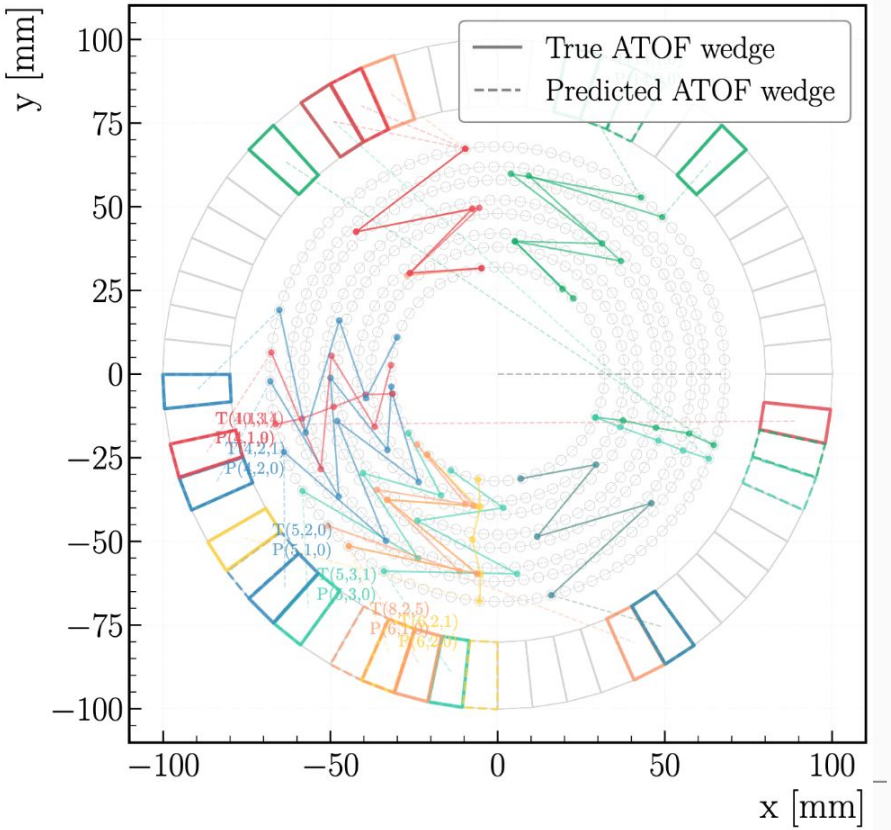


Evaluation on Simulation

good predictions

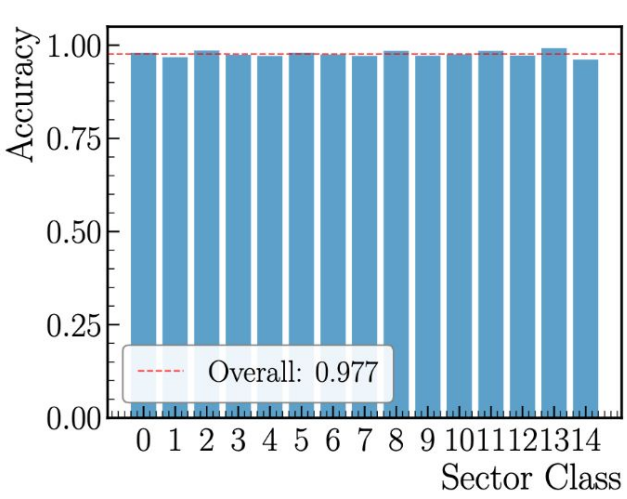


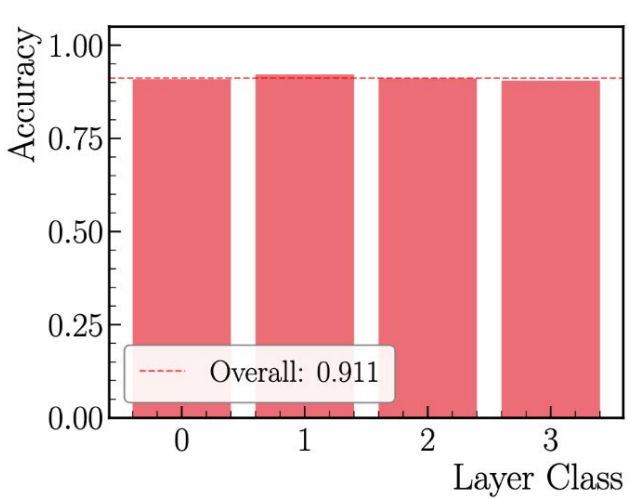
bad predictions

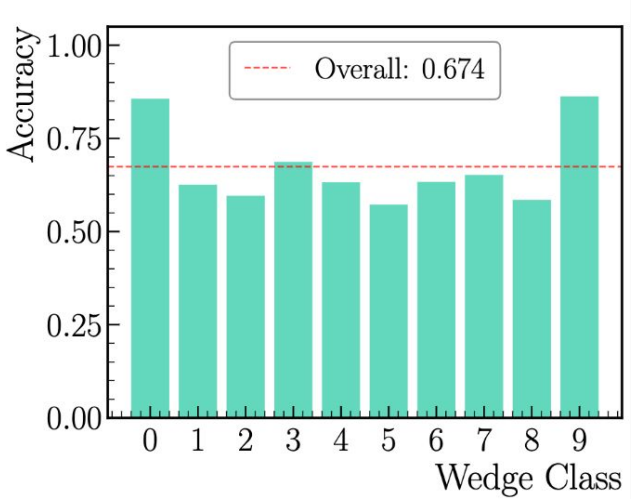


Evaluation on Simulation

- Accuracy per class (sector, layer and wedge)

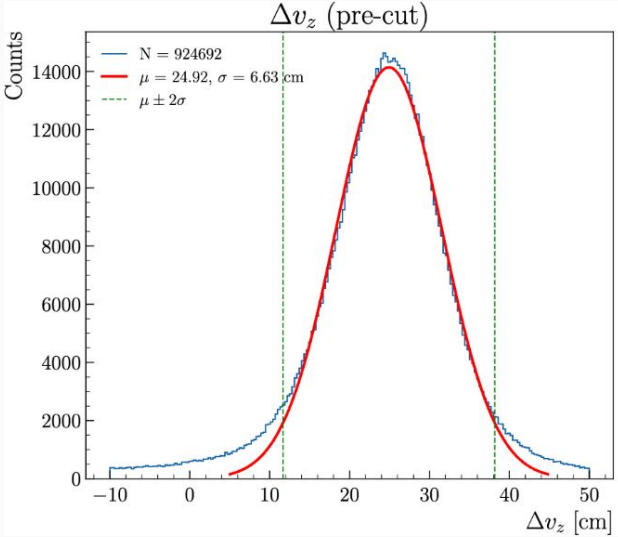


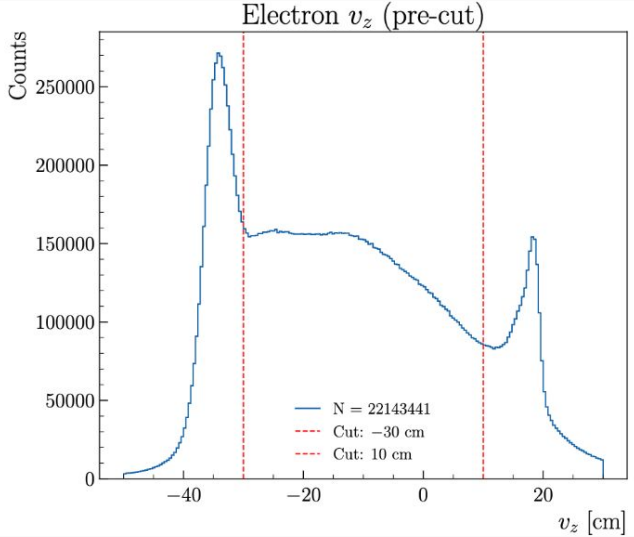


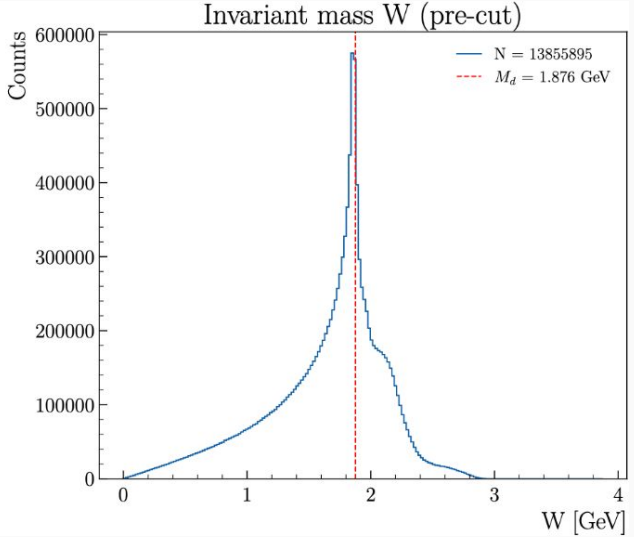


Evaluation on Real Data

- Deuterium elastic event (2.2 GeV run) selection

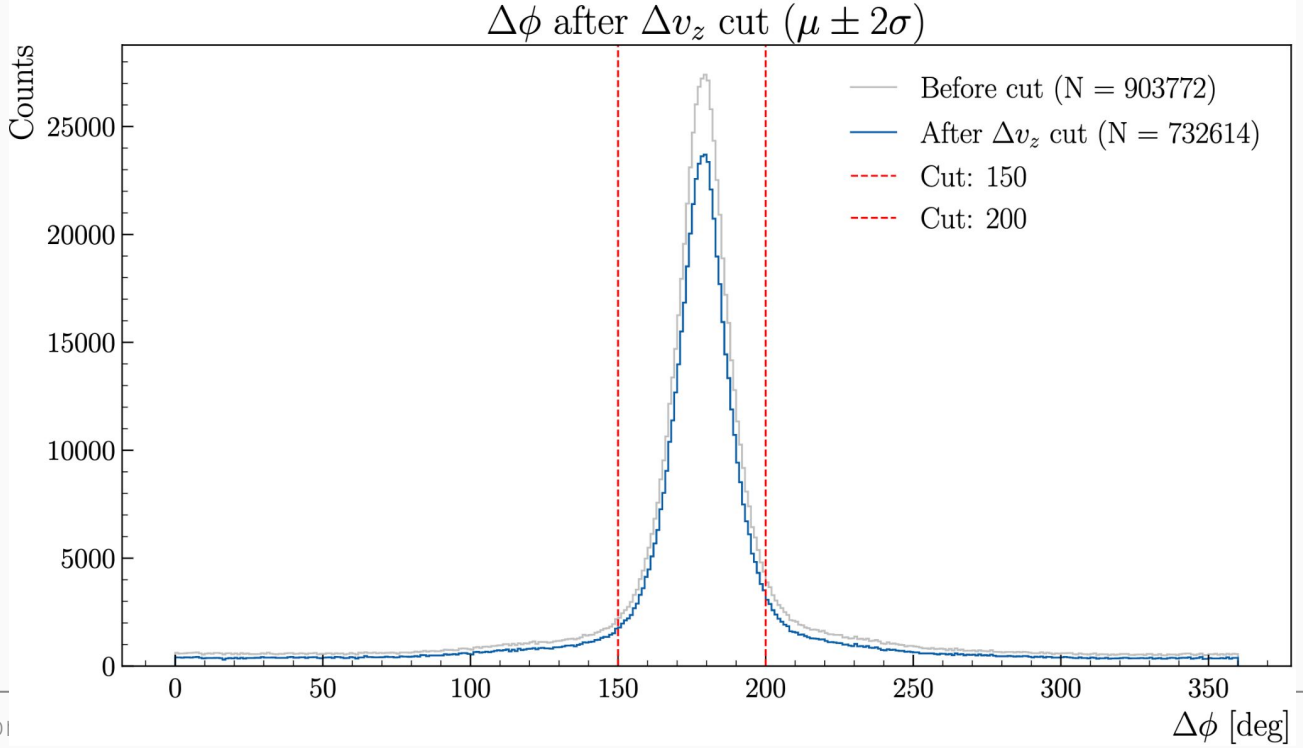






Evaluation on Real Data

Estimate the wedge that should be hit based on the electron kinematics and use it as the truth



Evaluation on Real Data

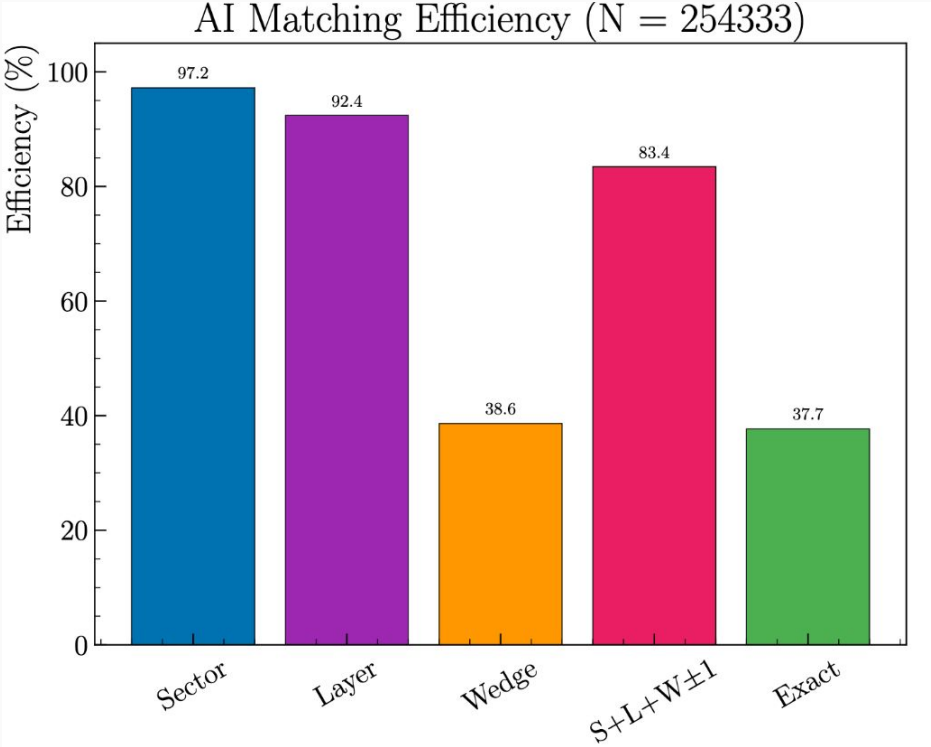
$$\text{Efficiency} = \frac{N_{\text{correctly matched}}}{N_{\text{true matchable}}}$$

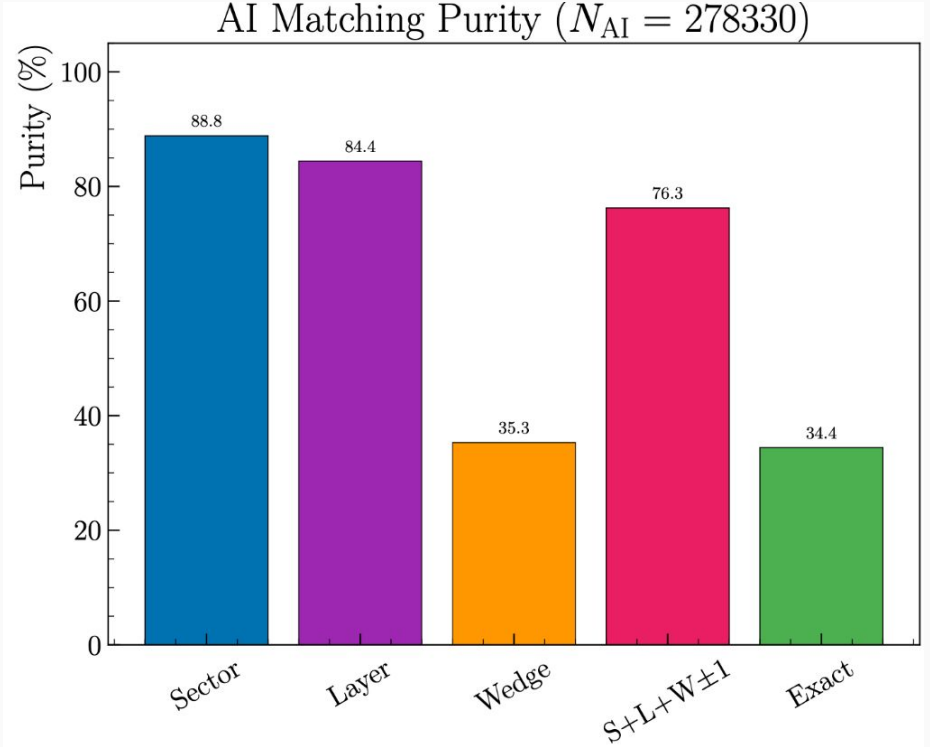
- $N_{\text{true matchable}}$: Number of AHDC tracks that genuinely hit a specific ATOF sector
- $N_{\text{correctly matched}}$: Number of those tracks where the predicted = true
- This answers: "Of all tracks that should have been matched, what fraction did we correctly find?"

$$\text{Purity} = \frac{N_{\text{correctly matched}}}{N_{\text{candidates}}}$$

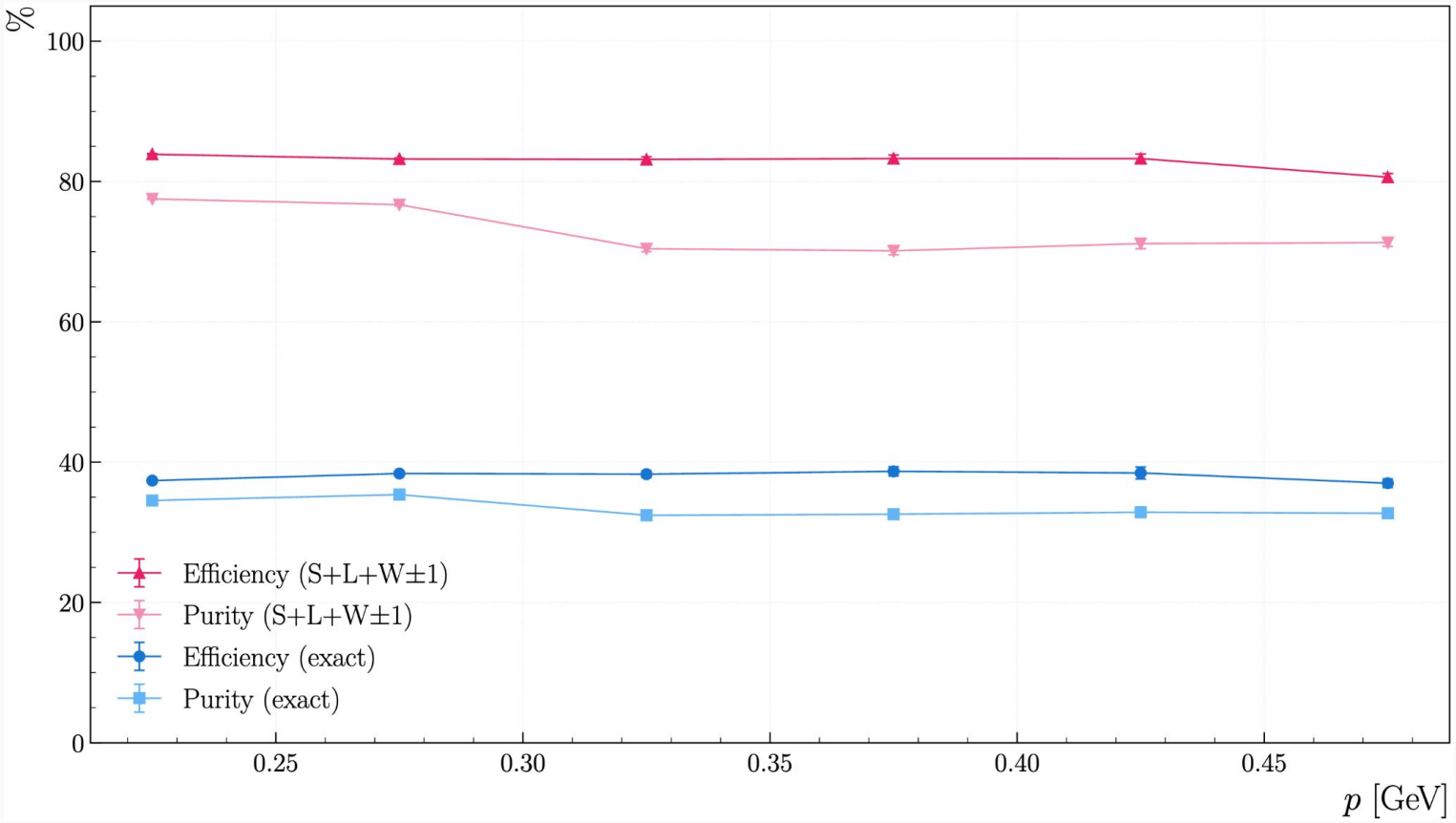
- $N_{\text{candidates}}$: Number of tracks the model assigns to a given class, regardless of whether that assignment is correct or not.
- This answers: "Of all tracks the model selected as matches, what fraction are genuine?"

Evaluation on Real Data





Evaluation on real data



Summary and Outlook

- An AI-assisted MLP has been developed for track matching between AHDC and ATOF:
  - The network have been optimized and 3 heads to predict the sector, layer and wedge have been used
  - The AI is already implemented in COATJAVA and have been used in cooking
  - Evaluated the model's efficiency and purity as a function of momentum on simulation and data
  - Efficiency is always higher than 80% on data / 90% on simulation

- Future work:
  - Retrain the track finding and track matching with the updated geometry

Backup slides

Evaluation on simulation

- Detail errors: good accuracy for sector and layer, wedge can be off by one