# UniTrackFormer: End-to-End TrackML Particle Tracking with Transformer

Ivan Tang

May 2025

# Project Overview

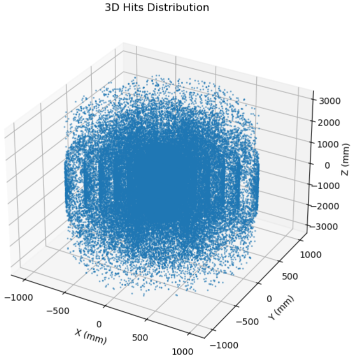
- **Goal:** End-to-end particle track reconstruction for the TrackML Challenge using deep learning.
- **Core Idea:** Use Transformer architecture to cluster detector hits into physical tracks.
- **Key Contributions:**
  - End-to-end modeling, no manual feature engineering
  - Multi-task loss: classification, clustering, and parameter regression
  - Rich visualization and evaluation

# Data Structure

**TrackML Raw Data:**

- `hits.csv`: Each hit's spatial coordinates (x, y, z), module info, etc.
- `truth.csv`: True particle ID (particle_id) for each hit
- `detectors.csv`: Detector geometry info

**Feature Example:**



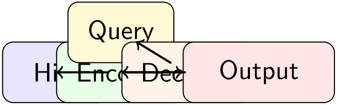
# Data Table Example

| hit_id | x | y | z | volume_id | module_id |
|---|---|---|---|---|---|
| 1 | 123.4 | -56.7 | 789.0 | 8 | 12 |
| 2 | 234.5 | -67.8 | 800.1 | 8 | 13 |
| ... | ... | ... | ... | ... | ... |

Table: Sample fields from hits.csv

# Model Architecture: UniTrackFormer

- **Input:** $N_{hits} \times D$ features
- **Encoder:** Multi-layer Transformer Encoder
- **Query:** $Q$ learnable query vectors
- **Decoder:** Multi-layer Transformer Decoder
- **Output:**
  - Track classification
  - Hit assignment (clustering)
  - Parameter regression

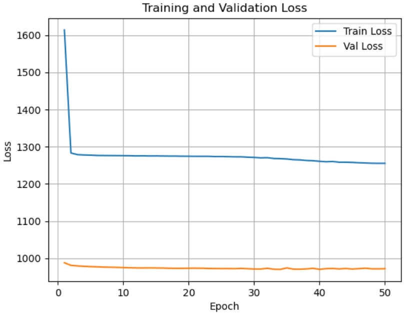


# Multi-task Loss

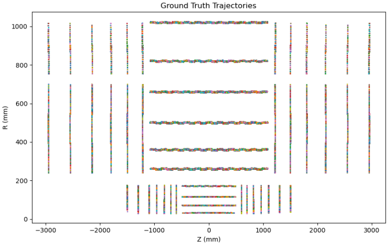
- **Track classification loss** (Binary Cross Entropy)
- **Mask clustering loss** (Dice + BCE)
- **Physical parameter regression loss** (MSE)
- Total loss $= \alpha$ classification $+ \beta$ mask $+ \gamma$ params

# Training and Evaluation

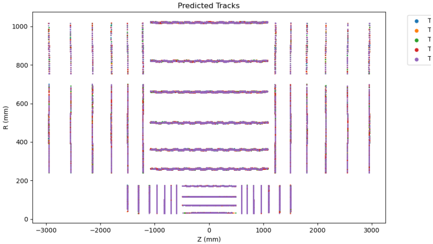
1. Data loading and feature extraction
2. Model training (supports K-fold cross-validation)
3. Evaluation metrics: efficiency, fake rate
4. Visualization: 3D distribution, rz projection, track clustering



# Visualization Results




Ground Truth Tracks




Predicted Tracks

# Summary and Outlook

- End-to-end TrackML tracking pipeline implemented
- Multi-task loss and rich visualization supported
- Future: optimize model, improve clustering, enhance physics interpretability

**Thank you! Questions welcome.**