T 28: Data, AI, Computing, Electronics III

Time: Tuesday 16:15–18:45 Location: KH 00.024

T 28.1 Tue 16:15 KH 00.024

Multi-Modal track reconstruction using Graph Neural Networks at Belle II — •Tristan Brandes[1], Torben Ferber[1], Giacomo De Pietro[1,2], and Lea Reuter[1] — [1]Institute of Experimental Particle Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Scientific Computing Center, Karlsruhe Institute of Technology, Karlsruhe, Germany

Large backgrounds and detector aging impact the track finding in the Belle II central drift chamber, reducing both purity and efficiency in events. This necessitates the development of new track algorithms to mitigate detector performance degradation. Building on our previous success with an end-to-end multi-track reconstruction algorithm for the Belle II experiment at the SuperKEKB collider (arXiv:2411.13596), we have extended the algorithm to incorporate inputs from both the drift chamber and the silicon vertex tracking detector, creating a multi-modal network. We employ graph neural networks to handle the irregular detector structure and object condensation to address the unknown, varying number of particles in each event. This approach simultaneously identifies all tracks in an event and determines their respective parameters.

We have fully integrated this algorithm into the Belle II analysis software framework. Utilizing a realistic full detector simulation, which includes beam-induced backgrounds and detector noise derived from actual collision data, we report the performance of our track-finding algorithm across various event topologies compared to the existing baseline algorithm used in Belle II.

T 28.2 Tue 16:30 KH 00.024

Graph Neural Networks for multi-hypothesis clustering in the Belle II Electromagnetic Calorimeter to improve hadron clustering — •Jonas Eppelt and Torben Ferber — Karlsruhe Institute for Technology

The Belle II experiment at the SuperKEKB collider in Tsukuba, Japan, studies the products of e^+e^- collisions to probe the Standard Model and search for new physics. Many of these processes involve π^0, which almost always decay into two γ, and reconstructing these correctly is Important for many analyses. The currently used clustering algorithm is optimized towards the reconstruction of photon clusters, which form regular, mostly round clusters. However, the e^+e^- collisions also produce hadronic particles, which also interact in the calorimeter. As their energy depositions are more irregularly shaped and can produce split-off particles, which create disconnected, additional clusters, they pose a significant challenge for any clustering optimized for electromagnetic clusters. Improving upon their reconstruction would not only improve their identification, but also help constrain the energy in the calorimeter to the collision energy. I will show an implementation of a graph neural network, optimized for both photon and hadron reconstruction. Not only does it improve the photon energy resolution, but it also improves the hadron position reconstruction. Further, I will demonstrate the improved constraints on the energy in the calorimeter on the collision energy.

T 28.3 Tue 16:45 KH 00.024

Point Cloud Segmentation for the Belle II GNN-Based Tracking — •Daniel Grossmann, Tristan Brandes, Giacomo De Pietro, Torben Ferber, and Lea Reuter — Institute of Experimental Particle Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany

Our implementation of an end-to-end multi-track based reconstruction algorithm for the Belle II experiment at the SuperKEKB collider improves the tracking performance compared to the baseline algorithm (arXiv:2411.13596). It combines the Object Condensation algorithm with a Graph Neural Network that simultaneously identifies all tracks in an event and determines their respective parameters. However, our current algorithm is based on a segmentation step during the model post-processing, which fails to capture specific signatures for more complex track topologies.

This work improves the segmentation by employing a pointcloud-based model in the post-processing step for the track and hit assignment. We report the performance of our improved track-segmentation algorithm across various event topologies compared to the existing segmentation method and to the baseline tracking algorithm used in Belle II.

T 28.4 Tue 17:00 KH 00.024

Graph Neural Network based inclusive flavour tagger at the LHCb experiment — •Yukai Zhao[1], Sara Celani[2], Stephanie Hansmann-Menzemer[1], and Pelian Li[3] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Germany — [2]CERN, Switzerland — [3]University of Chinese Academy of Sciences, China

The study of CP violation at the LHCb experiment is essential for understanding the observed matter*antimatter asymmetry in the universe. A key component of many such measurements is the decay-time-dependent analysis of oscillating neutral B mesons, which requires knowledge of the b-hadron flavour at production. This initial flavour information can not be determined directly from the decay products of the signal candidate. Instead, it is inferred using flavour tagging algorithms which exploit correlations with other particles produced in the same proton*proton collision. This talk presents a novel flavour-tagging method based on Graph Neural Networks (GNNs). The approach leverages the Deep Full Event Interpretation framework, which performs inclusive reconstruction of heavy hadrons in the event. By modelling the relationships between particles identified through inclusive reconstruction, the GNN-based tagger is expected to enhance the usage of kinematic and topological information, leading to a significant improvement in the estimated flavour-tagging performance. The results represent a promising advancement for time-dependent CP violation measurements at LHCb.

T 28.5 Tue 17:15 KH 00.024

Machine-Learning based Energy Regression of Muon Detector Showers in CMS — •Mascha Hackmann, Ayse Asu Guvenli, Karim El Morabit, and Gregor Kasieczka — University of Hamburg, Hamburg, Germany

Exotic Long-Lived Particles (LLPs), predicted by many extensions of the Standard Model, can travel macroscopic distances before decaying. Decays inside the muon system of the CMS detector produce hadronic showers instead of isolated muon tracks, leading to unconventional signatures beyond the scope of standard muon reconstruction.

This talk presents a machine learning approach to analyze Muon Detector Showers (MDS) originating from LLP decays in the CMS experiment. For the analysis of the MDS, the Cathode Strip Chambers are interpreted as a sampling calorimeter. Low-level hit information is used as input to train a ParticleNet based Dynamic Graph Convolutional Neural Network (DGCNN) to regress the energy of the LLP. These studies provide insight to improve future searches for LLPs that decay in the muon system of the CMS.

T 28.6 Tue 17:30 KH 00.024

Machine-Learning Based Reconstruction of Muon Detector Showers in CMS — •Ayse Asu Guvenli, Karim El Morabit, Gregor Kasieczka, and Mascha Hackmann — University of Hamburg, Hamburg, Germany

Long-lived particles (LLPs) appear in many extensions of the Standard Model and can travel measurable distances before decaying. When such decays occur in or near the CMS muon system, they can produce atypical showers of hits rather than standard muon signatures. These muon detector showers (MDS) offer a promising handle for LLP searches but remain difficult to reconstruct with algorithms optimized for muons.

This work explores machine-learning based reconstruction of shower-like hit patterns in the CMS Cathode Strip Chambers, aiming to improve the identification and characterization of MDS from LLP decays. We present ongoing developments toward low-level hit reconstruction with ML methods and discuss their potential to enhance the sensitivity of Run-3 LLP searches.

T 28.7 Tue 17:45 KH 00.024

Reconstructing missing transverse momentum for electroweak precision measurements at the ATLAS experiment — •Gabriel Sanchez Shestakova, Matthias Schott, Timo Saala, and Philip Bechtle — Physikalisches Institut, Bonn, Germany

We present first studies of a supervised Machine Learning (ML) approach for reconstructing missing transverse energy (MET) using Particle Flow (PF) information acquired from open Large Hadron Collider (LHC) data. Using simulated $W^+ \to \mu^+\nu$ events at $\sqrt{s} = 8$ TeV, we compute an event-level MET observable directly from PF objects by explicitly reconstructing transverse momentum components and forming an analytically calculated MET, which serves as a controlled regression target for the ML approach.

A fully connected multilayer perceptron (MLP) is trained on per-event PF momentum components, with variable-length PF collections handled via zero-padding to a fixed input dimension. We also develop a graph neural network (GNN) approach that operates on variable-size PF representation. Quantile-based selections on the number of PF objects and on the calculated MET are applied prior to training in order to mitigate outliers and reduce input distribution mismatches.

T 28.8 Tue 18:00 KH 00.024

Secondary Particle Tracking with Graph Neural Networks for the ATLAS Experiment — •Hannah Schlenker, Sebastian Dittmeier, and André Schöning — Physikalisches Institut, Universität Heidelberg, Germany

The increased number of simultaneous proton-proton collisions in the upcoming High Luminosity LHC will increase the computational demands for charged particle track reconstruction in the new Inner Tracker (ITk) of the ATLAS Experiment. To reduce computing resources, the usage of parallel architectures like GPUs are investigated, and new track reconstruction algorithms based on machine learning are in development. Track finding on the basis of Graph Neural Networks (GNNs) has been shown to be promising [1]. This method constructs a graph based on all hits of an event using a module map, assigns a score to each edge and finds track candidates based on these scores.

Previous work focused on particle tracks originating near the interaction region [1]. Secondary particle tracks, which are produced all over the detector, have not been targeted. A good track finding efficiency for these particles is important for enhanced energy measurements, characterisations of material interactions and potential searches of long-lived particle decays.

This talk discusses the secondary tracking performance of current models and of new models developed specifically for this task.

[1] ATLAS Collaboration, Optimizations of the ATLAS ITk GNN reconstruction pipeline, tech. rep., CERN, 2025, URL: https://cds.cern.ch/record/2948192

T 28.9 Tue 18:15 KH 00.024

Keeping Track of Graphs: 4D Tracking with Graph Neural Networks at Muon Colliders — •Lukas Bauckhage — Deutsches Elektronen-Synchrotron DESY — Physikalisches Institut, Universität Bonn

This talk explores the application of Graph Neural Networks (GNNs) to track reconstruction at a future muon collider experiment utilising precise timing information. We highlight the challenges posed by high beam-induced backgrounds, making robust and efficient tracking exceptionally difficult. We demonstrate how GNNs can effectively model the 4D relationships among detector hits to identify and group related hits by leveraging spatial and timing information to distinguish true particle trajectories from background activity. Our results on the performance of reconstruction algorithms aided by GNNs compared to established algorithms purely based on Kalman-Filters are presented.

T 28.10 Tue 18:30 KH 00.024

Machine Learning Models for Separating Signal and Background Events in LHC pp Collisions — Oleksandr Shekhovtsov, André Sopczak, and •Lukas Vicenik — CTU in Prague

We investigate machine-learning-based signal-background discrimination for measuring Higgs boson production in association with top quarks (ttH) in multilepton final states at $\sqrt{s} = 14$ TeV. We simulated a dataset for a generic detector that mimics a realistic analysis. Low low-level features are used. A range of methods from standard Machine Learning models to advanced approaches inspired by geometric deep learning are benchmarked. The study evaluates these approaches, highlighting their performance and identifying directions for improving symmetry-aware machine learning in collider measurements.