

Graph Neural Network based Track Finding in the Central Drift Chamber

B2GM Trigger

Lea Reuter, Philipp Dorwarth, Torben Ferber, Slavomira Stefkova | Friday 2nd June, 2023



Project members: Machine Learning for Trigger



KIT (ETP)

L. Reuter, I. Haide, P. Dorwarth,
P. Ecker, S. Stefkova, T. Ferber



KIT (ITIV)

M. Neu, K. Unger, J. Becker

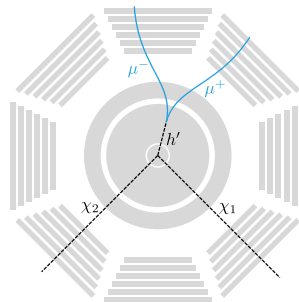
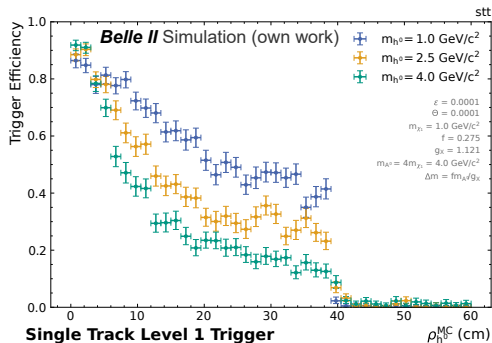


MPI (MPP)

E. Schmidt, F. Meggendorfer, C. Kiesling



Displaced vertices important signature in searches for new physics ¹



→ Improve both real-time ($< 2 \mu\text{s}$) reconstruction and offline reconstruction

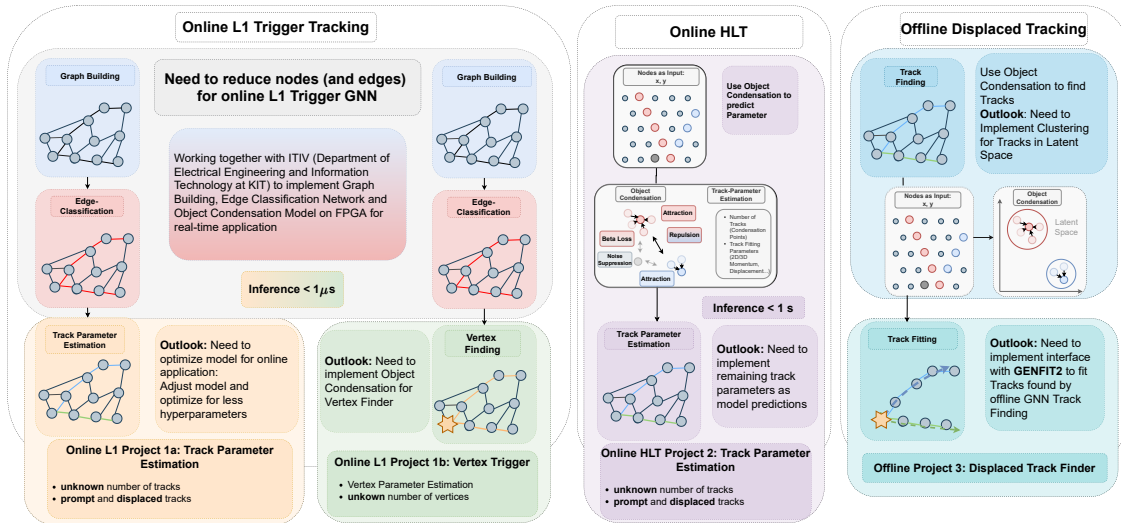
¹ Long-lived Dark Higgs and Inelastic Dark Matter at Belle II (arXiv:2012.08595)

GNN Tracking Project Overview

ETP: L. Reuter, I. Haide, P. Dorwarth, P. Ecker, S. Stefkova, T. Ferber

ITIV: M. Neu, K. Unger, J. Becker

MPI: E. Schmidt, F. Meggendorfer, C. Kiesling



GNN Model Architecture

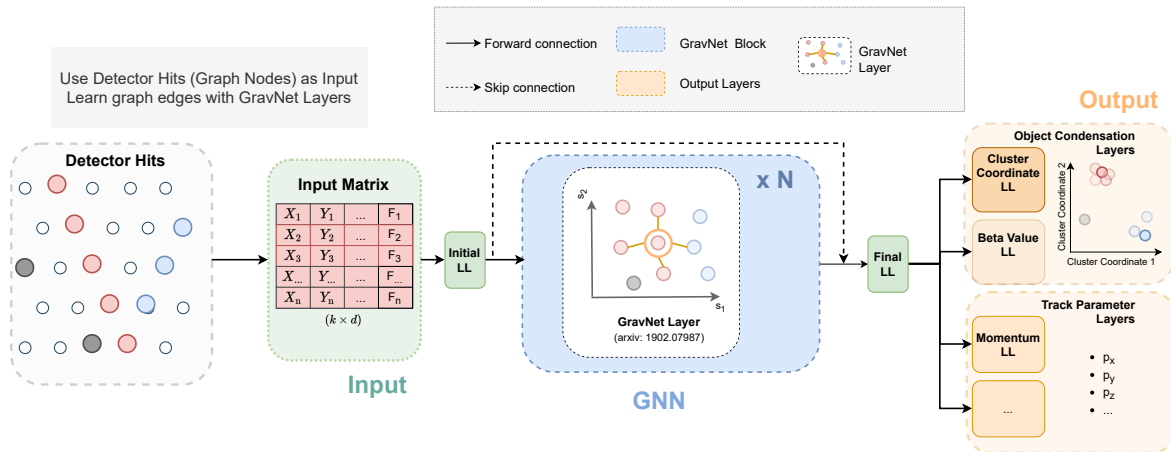
Challenges:

- Computing resource and time constraint → Graph Neural Networks
- Find unknown number of tracks → Object Condensation ([arXiv:2002.03605](https://arxiv.org/abs/2002.03605))

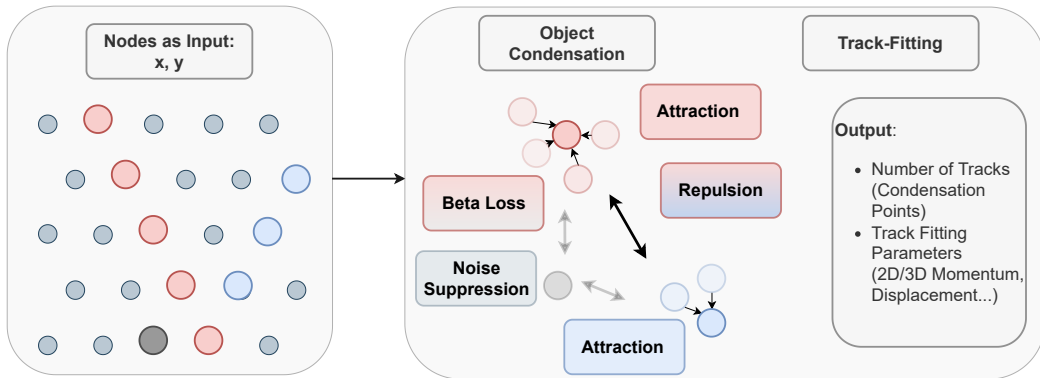
GNN Model Architecture

Challenges:

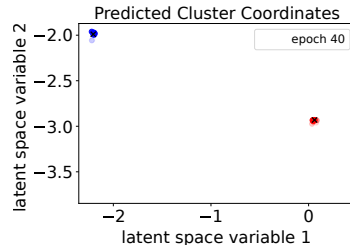
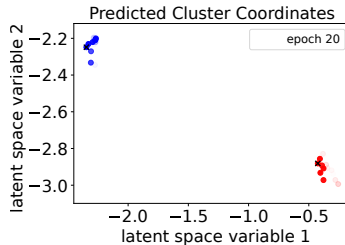
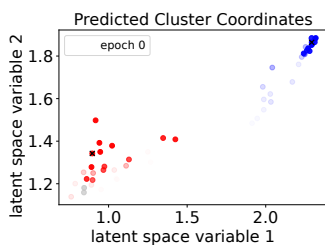
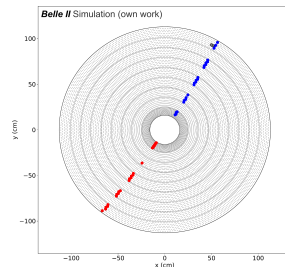
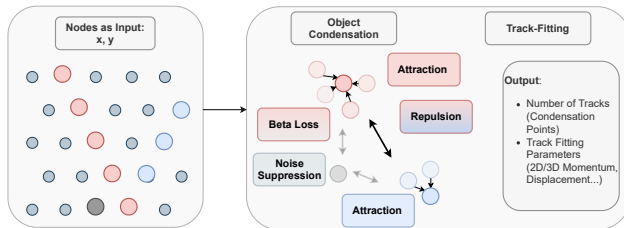
- Computing resource and time constraint → Graph Neural Networks
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Object Condensation

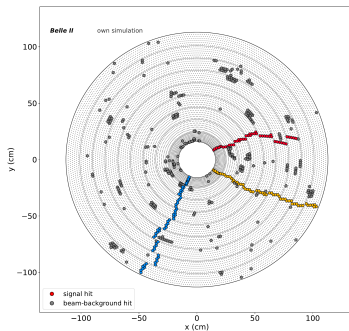


Object Condensation: Track Fitting

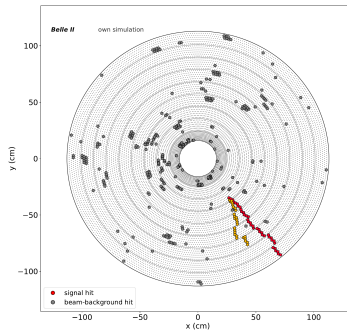


Combined Training

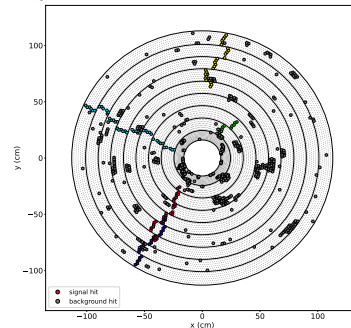
- **Prompt** (non-displaced) samples
- Between 1 to 5 μ^- and μ^+



- Displaced vertex samples, always **2 tracks**
- displacement v_r up to **100 cm displacement**



- Displaced samples, tracks starting points to interaction point
- Between 1 to 5 μ^- and μ^+
- displacement v_r up to **100 cm displacement**



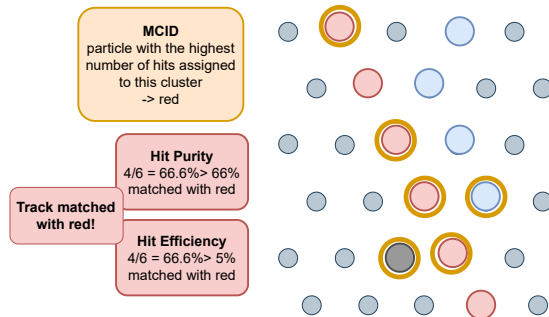
Current MC Matching for Object Condensation

We want to make the comparison fair with (offline) tracking: values taken from tracking paper

- match particle with the highest assigned number of hits to track
- hit purity > 66% required
- hit efficiency > 5% required (curlers)

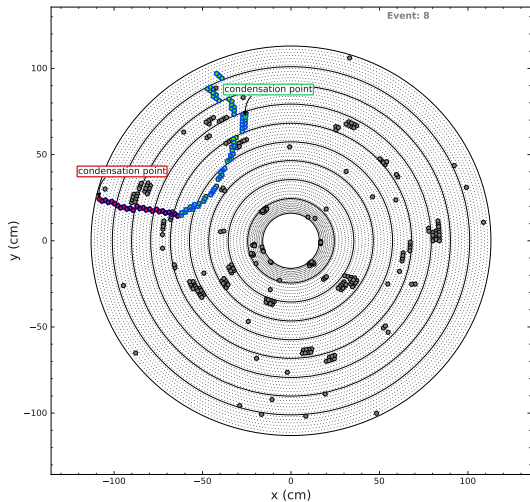
If it does not match, its **fake**

For **clones** (multiple tracks per particle id), take highest purity and then highest efficiency as true matched track

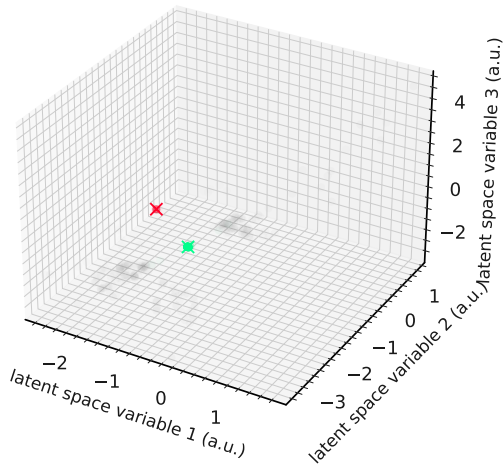


Is there something similar for Trigger Tracks?

Event Display with Clustered Latent Space



Achieving high hit purity and high hit efficiency



Comparison with basf2

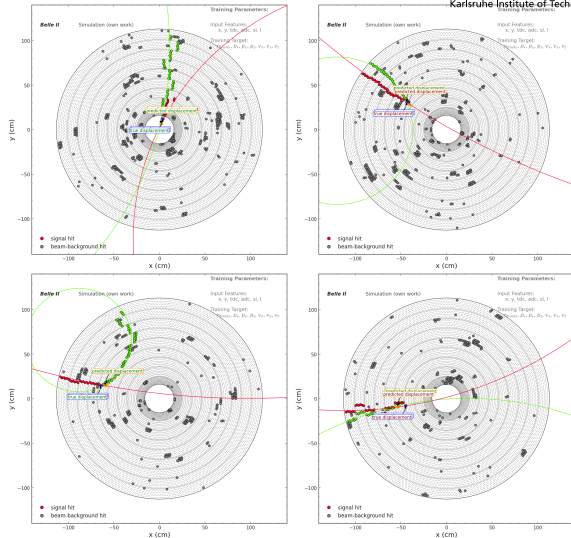
Updated MC Matching

Now GNN MC Matching criteria for Tracks is the same as for B2 Offline

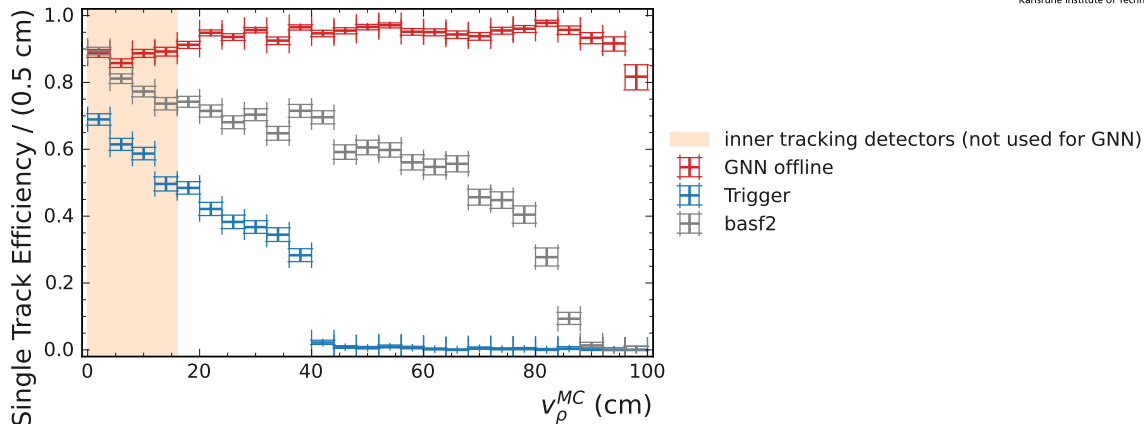
Track Object of	GNN	TRGCDC Neuro- Tracks	B2 Offline
Displaced Vertex			
Efficiency	97.1 %	26.7 %	64.4%
Fake Rate	2.5 % ^a	0.0 %	8.7%
Clone Rate	1.1 %	0.1 %	1.7%
Prompt			
Efficiency	99.3%	97.0 %	99.96 %

$$\text{Efficiency: } \frac{\text{Found Signal Tracks}}{\text{All Signal Tracks}}$$

^alargest part of fake tracks consists of tracks that currently do not match the tracking purity requirement of 66% or hit efficiency of 5%



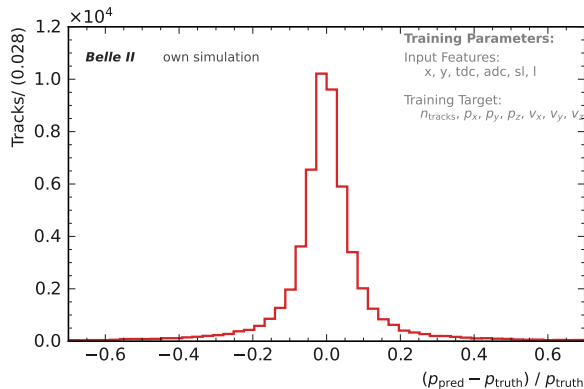
Displaced Track Finding Efficiency



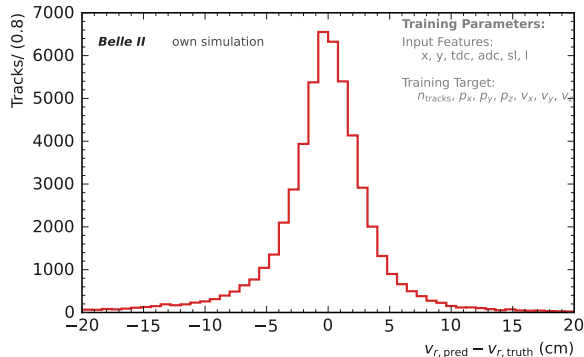
Displaced vertex samples,
 $X \rightarrow \mu^+ \mu^-$, $m_X = [1, 2, 3]$ GeV,
 $0.9 \text{ GeV} < p_X < 6 \text{ GeV}$,

Track Parameter Resolution on Displaced Samples

Relative Momentum Resolution

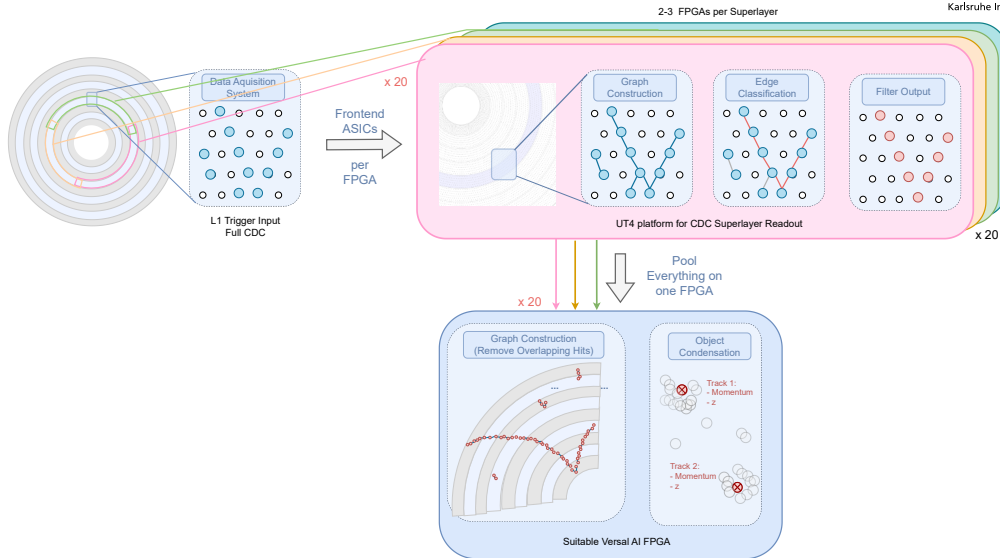


Resolution of the production vertex position of the track

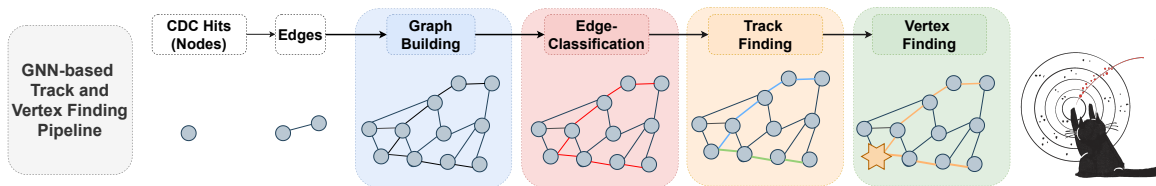


For L1 Trigger, the predicted track parameters would include p and dz (something else?)

Potential Trigger Pipeline: Idea



Summary and Outlook



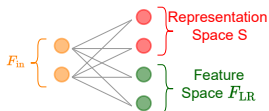
Current Status

- Developing GNN-based Track and Vertex Finding for **Offline** and **Online** (CPU and FPGA) Tracking
- Marc (ITIV) is working on the Graph Building implementation on FPGA
- Next steps: Minimizing the model for Edge Classification (2000 parameters) and Object Condensation (27 000 parameters)

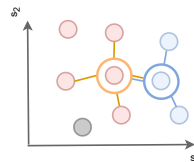
GravNet Layer

1.) Learn spatial and feature representation

1.)



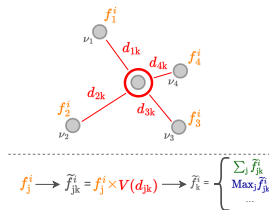
2.)



2.) Connect k nearest neighbours

3.) Message Passing

3.)



4.)



4.) Aggregate information and update nodes

Adapted from arXiv:1902.07987

Displaced Particle Gun Tracks: Latent Space and Position Prediction

