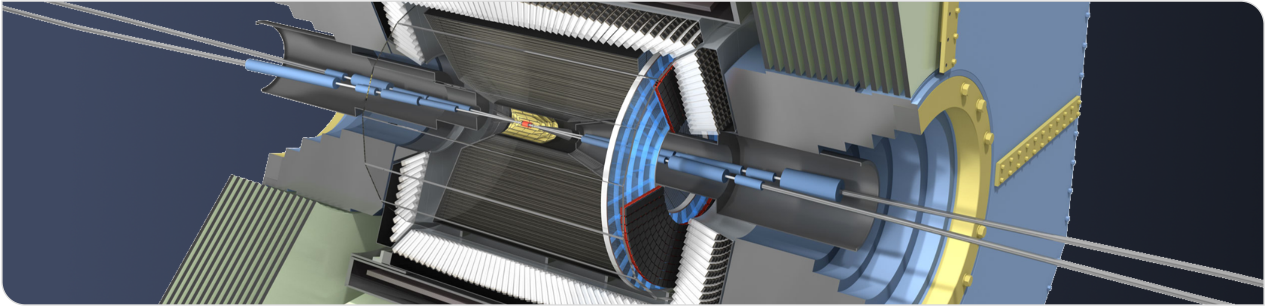
GNN-based Track and Vertex Finding at Belle II

26. Deutsche Physikerinnentagung: Physics Talks - Particle Physics Experiment

Lea Reuter - lea.reuter@kit.edu | 27th November 2022



Belle II Detector

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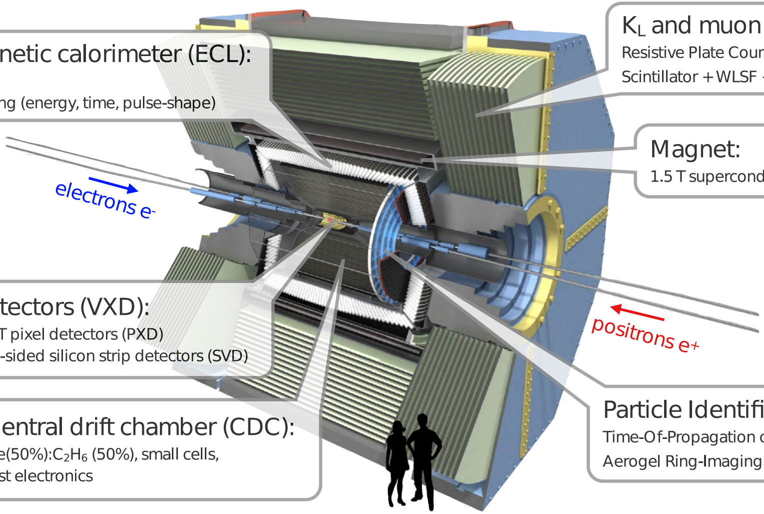


Electromagnetic calorimeter (ECL):
CsI(Tl) crystals
waveform sampling (energy, time, pulse-shape)

K_L and muon detector (KLM):
Resistive Plate Counters (RPC) (outer barrel)
Scintillator + WLSF + MPPC (endcaps, inner barrel)

Magnet:
1.5 T superconducting

Trigger:
Hardware: < 30 kHz
Software: < 10 kHz

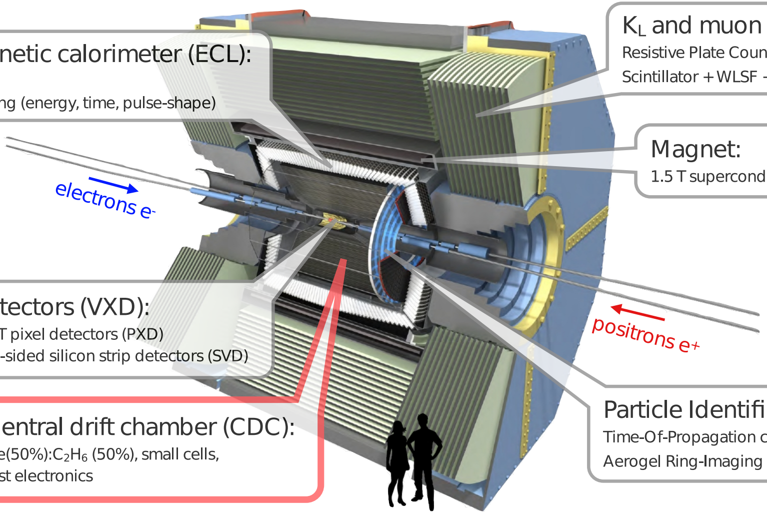
Vertex detectors (VXD):
2 layer DEPFET pixel detectors (PXD)
4 layer double-sided silicon strip detectors (SVD)

Central drift chamber (CDC):
$He(50\%):C_2H_6$ (50%), small cells,
fast electronics

Particle Identification (PID):
Time-Of-Propagation counter (TOP) (barrel)
Aerogel Ring-Imaging Cherenkov Counter (ARICH) (FWD)

DEPFET: depleted p-channel field-effect transistor
WLSF: wavelength-shifting fiber
MPPC: multi-pixel photon counter

Belle II Main Tracking



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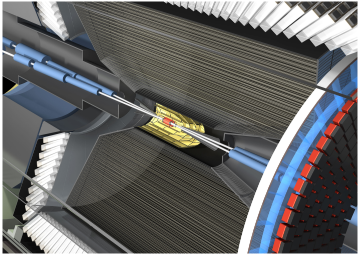
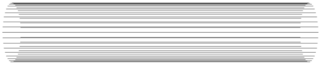
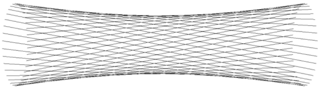




(a) An axial wire layer - sense wires are parallel to the beamline



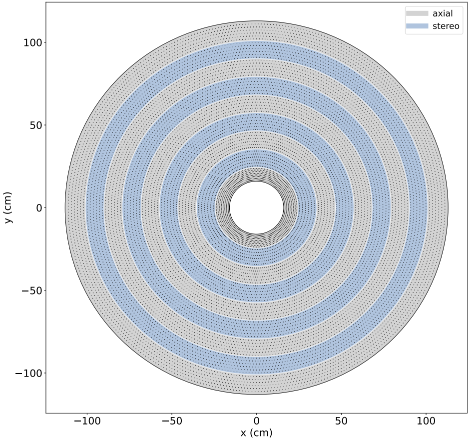
(b) A stereo wire layer - sense wires are skewed to the beamline (exaggerated)

- Main tracking detector of Belle II
- Sense wires are arranged parallel to the the beamline and the magnetic field (z-axis) to measure charged particles
- Information in z-direction is gathered from angled stereo layers

$\rightarrow$ **Focus on track reconstruction using the CDC hits**

arXiv:2003.12466

CDC x-y view



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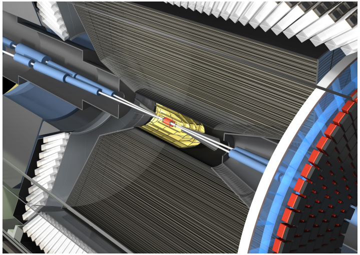

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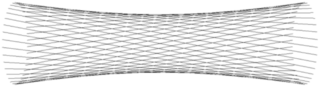

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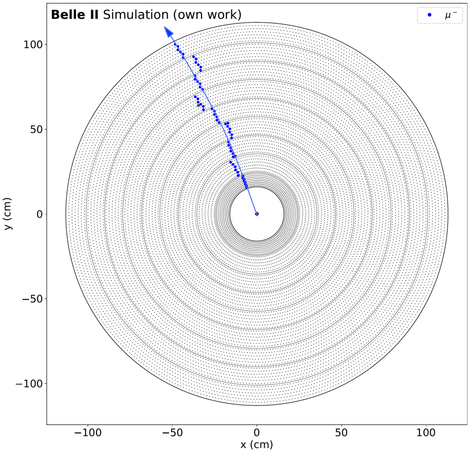

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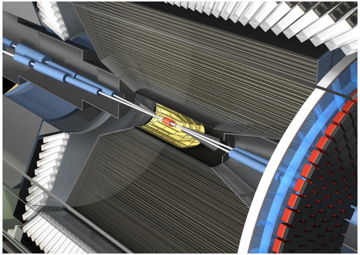

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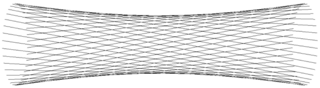

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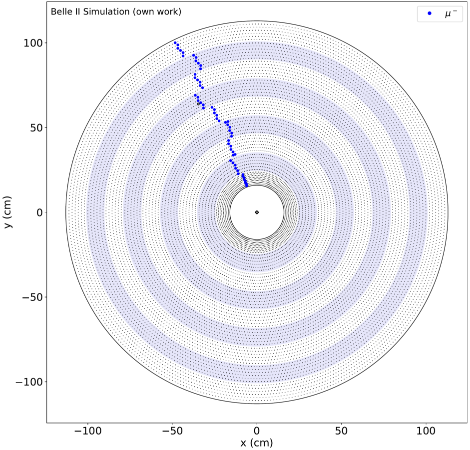

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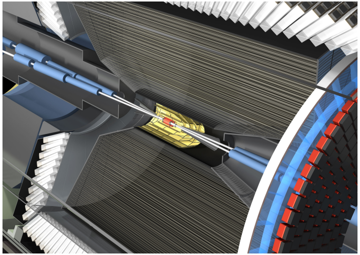
Karlsruhe Institute of Technology



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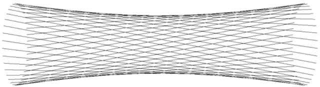

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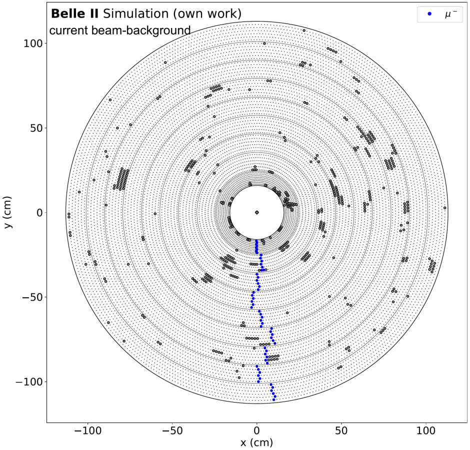

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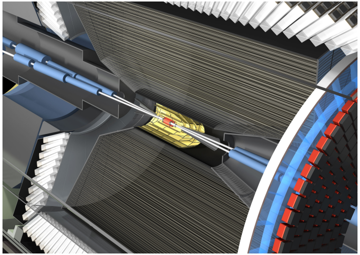

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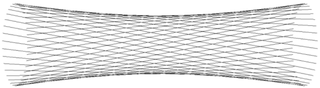

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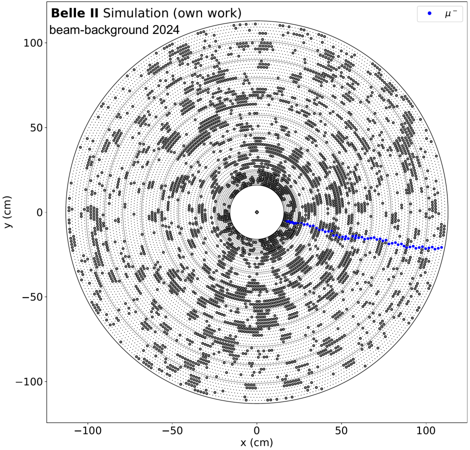
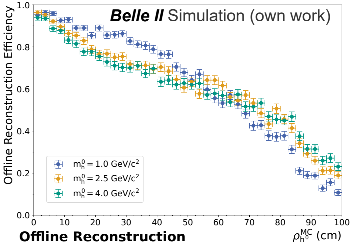
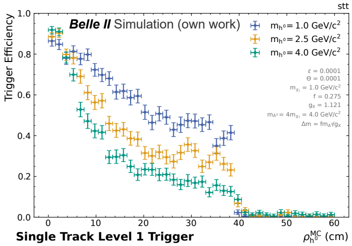
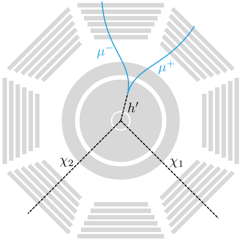


GNN-based Track and Vertex Finding





Credit: P. Ecker



Motivation:

Displaced vertices important signature in searches for new physics [a]

Challenge:

- Real-time ($< 2\,\mu$s) trigger and offline reconstruction [b] efficiency decreases depending on displacement (K_S^0, Λ^0, Dark Sector searches)
- Tracks with radial displacement larger than 40 cm are currently not saved by real-time single-track selection
- New track finding methods must be developed for expected high beam-background in 2024

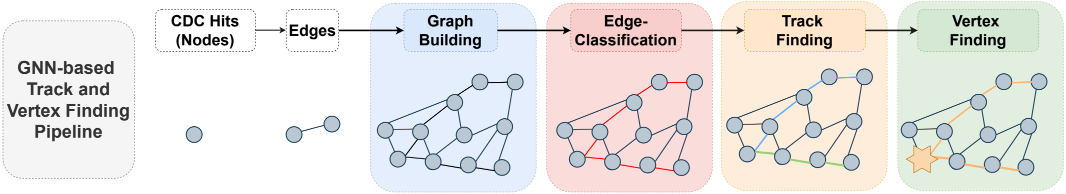
$\rightarrow$ **Improve both real-time reconstruction and offline reconstruction and develop real-time vertex finder with Graph Neural Networks (GNN)**

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

[b] https://github.com/belle2/basf2

Approach with Graph Neural Networks

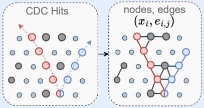
Variable number of CDC hits $\rightarrow$ utilize Graphs and Graph Neural Networks (GNN)



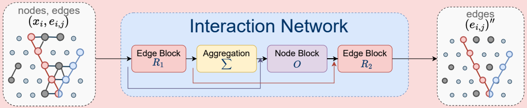
Approach with Graph Neural Networks

Karlsruhe Institute of Technology

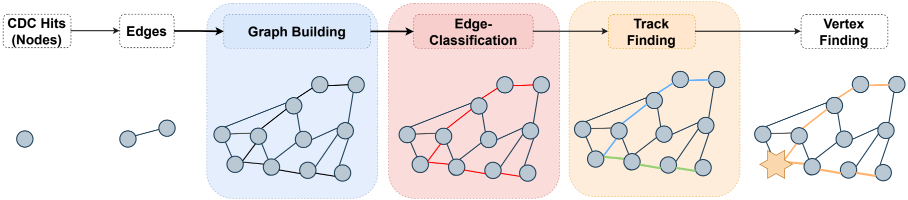
- Efficient and fast graph building needed



- Cleanup beam-background with **Interaction Network** (arxiv:2112.02048)



GNN-based Track and Vertex Finding Pipeline



- Find tracks using **Object Condensation** (arXiv:2002.03605)
- **Goal**: predict Track Fitting parameters and find condensation points

Approach with Graph Neural Networks: Track Finding

Karlsruhe Institute of Technology

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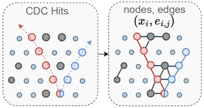

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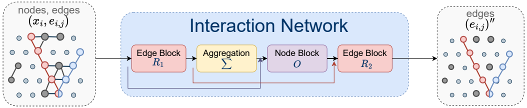

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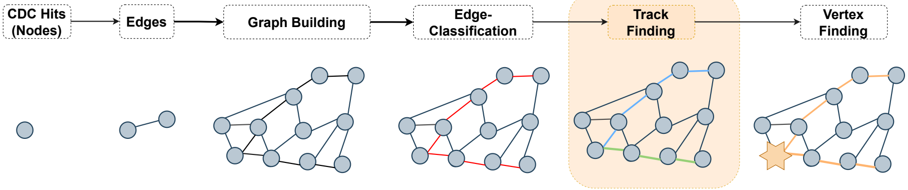

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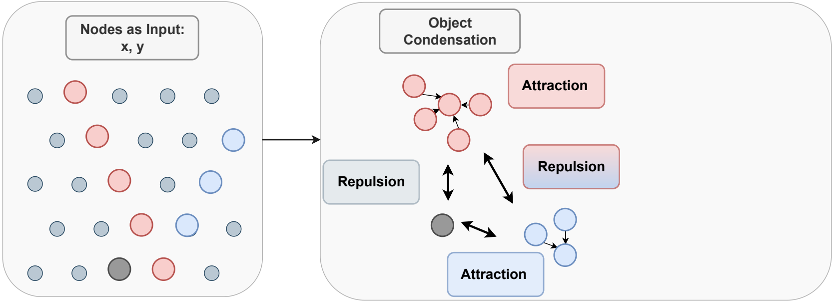
Object Condensation Track Finding Approach



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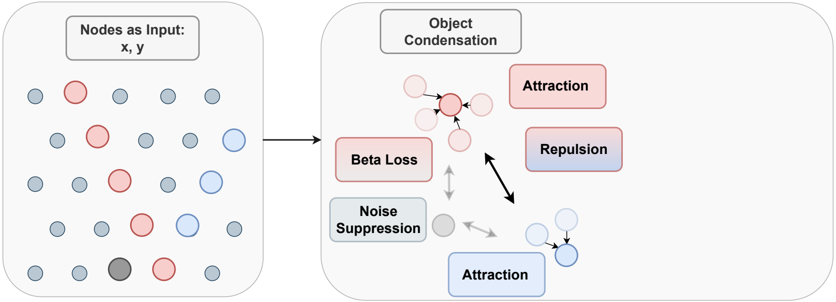

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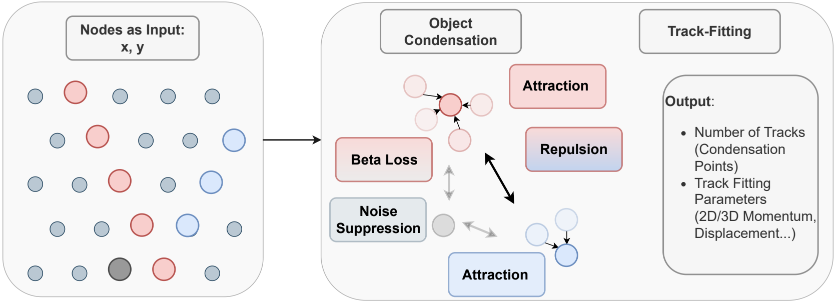

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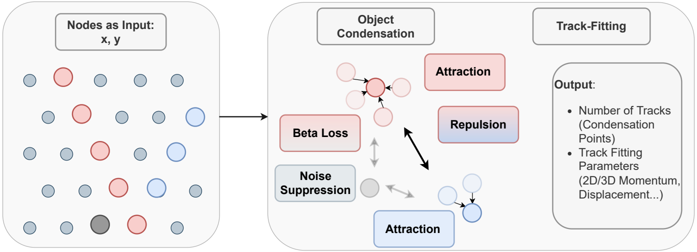
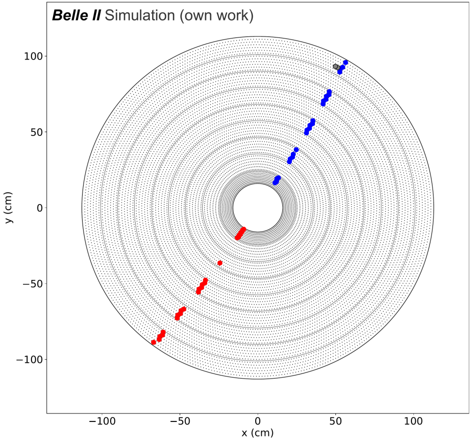


Start with a very simple case of two charged tracks originating from the interaction region in beam-background free environment ($e^+e^- \to \mu^+\mu^-$ with no beam-background)



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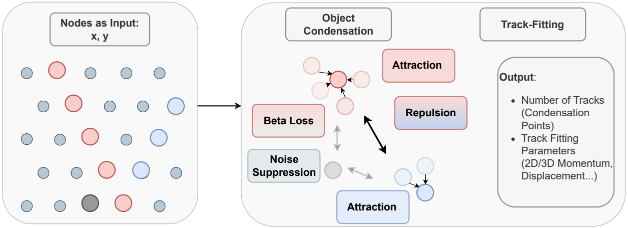

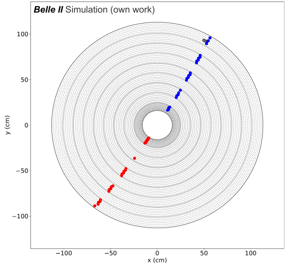

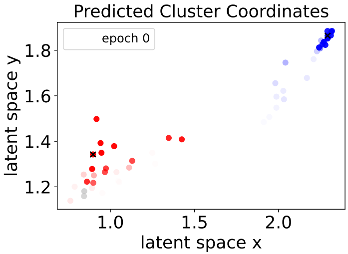

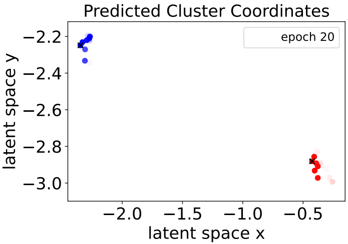

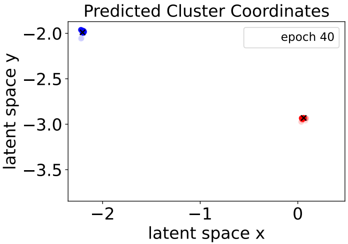

Object Condensation Track Finding

More realistic scenario:

Simulated samples:

- Between 1 to 3 μ^- and μ^+
- Starting with current (moderate) beam background conditions
- **Not** displaced
- $\theta = [30, 120]$, so within CDC
- Transverse momentum $p_t = [0.3, 5]$ GeV

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Training

- Trained on 12 000 samples
- Input features per node: Only use 2D-information CDC hit x, y position
- Predicting: **unknown** and **variable** number of tracks n_{tracks} and 3D-Momentum p_x, p_y, p_z

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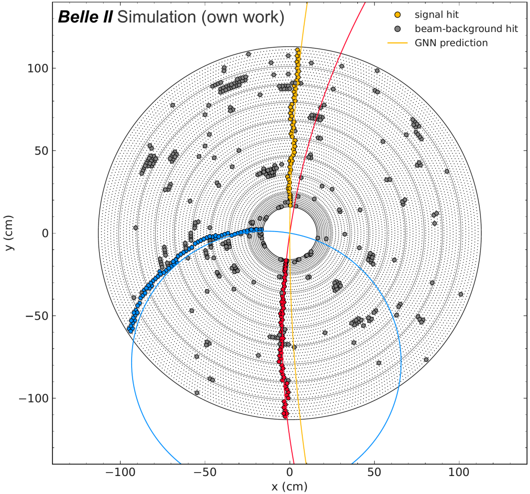
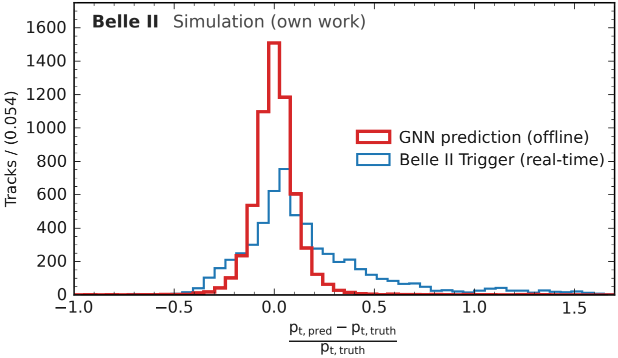
Assumption: Tracks starting at the Interaction Point, currently only momentum is predicted



Track Finding: Comparison with Online L1 Trigger

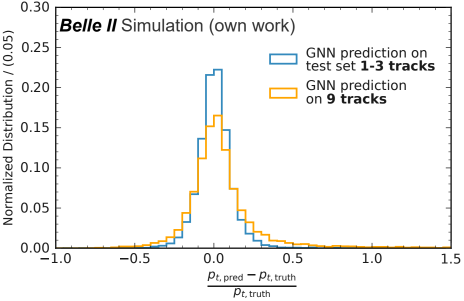
Found Tracks	GNN	Belle II Trigger
Only signal tracks	94.5%	93.7%
Missing signal tracks	1.2%	5.9%
All signal tracks and additional tracks[a]	3.7%	0.3%
Missing signal tracks and additional tracks[a]	0.6%	0.1%

[a] additional tracks include beam-background (real tracks), fake and duplicate tracks

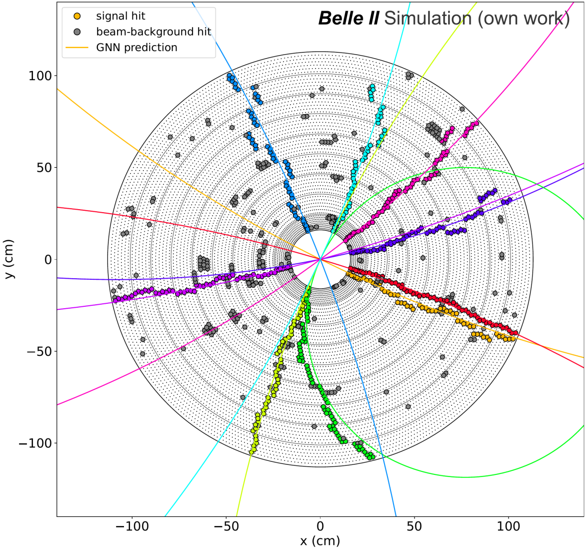


Track Finding: High Multiplicity Events

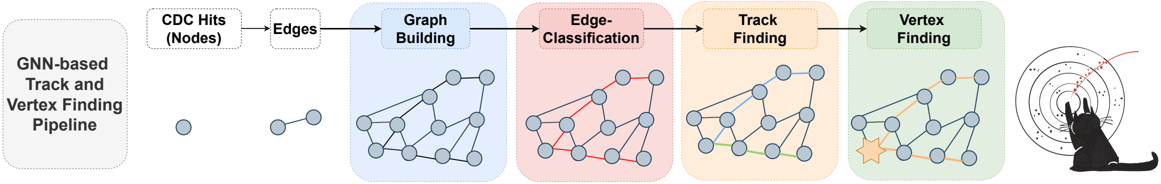
Object Condensation model is good in **generalizing**:
Evaluation of previously trained model on high multiplicity events (9 particles)



Promising results for GNN-based Tracking!



Summary and Outlook



Current Status

- Developing GNN-based Track and Vertex Finding Pipeline
- Performance measurement of different graph building methods and edge-classification
- Implemented Object Condensation for Drift Chamber Track Finding and testing on samples with current beam-background conditions

$\rightarrow$ **Have first full Track Finding and Fitting GNN model working**

Outlook

- Working together with ITIV (Department of Electrical Engineering and Information Technology at KIT) to implement Graph Building, Edge Classification Network and Object Condensation Model on FPGA for real-time application
- Extend Object Condensation to predict displaced tracks offline and online and develop Vertex Finding
- Evaluate Object Condensation on Data/MC for displaced vertex Example
  $e^+e^- \rightarrow \Phi\gamma,$
  $\Phi \rightarrow K_{S^0} K_{L^0}$