Belle II Germany Meeting 2024

Hardware/Upgrade Session

Belle II
Germany

Hardware/ Upgrade Session

09:00

Near-Term Upgrade Program for the Neuro-Track-Trigger — *Simon Hiesl*
Seminar room 3, Building 1B — 09:00 - 09:20

Optimized Inputs for the Neuro-Track-Trigger and Principles for a Displaced Vertex-Trigger — *Timo Forsthofer*
Seminar room 3, Building 1B — 09:20 - 09:40

10:00

Kai's Hardware Talk (3D-Hough and DVT) — *Kai Lukas Unger*
Seminar room 3, Building 1B — 09:50 - 10:10

CDC Hit Clean-up for Tracking — *Greta Heine*
Seminar room 3, Building 1B — 10:10 - 10:30

11:00

Object Condensation with Graph Neural Networks for the ECL Trigger - Status and Implementation — *Isabel Haide*
Seminar room 3, Building 1B — 11:00 - 11:20

News from the Onsen PXD readout system — *Dmytro Meleshko*
Seminar room 3, Building 1B — 11:20 - 11:40

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Upgrade of the Neural Network Track Trigger for Belle II

Simon Hiesl, Christian Kiesling, Kai Unger, Sebastian Skambraks, Timo Forsthofer

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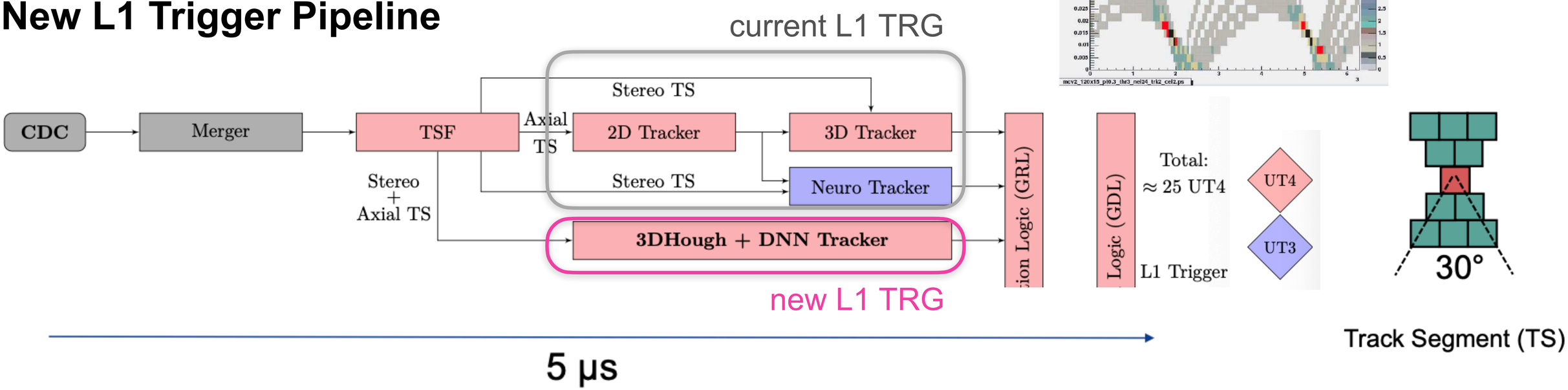
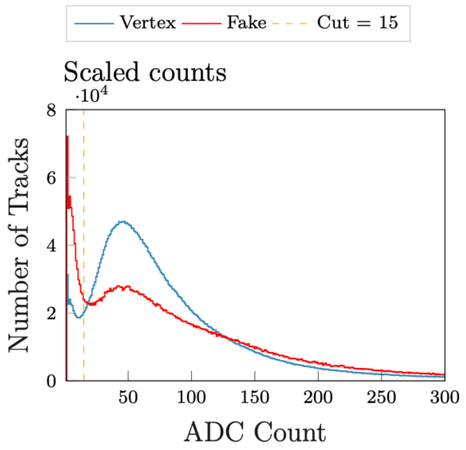
New L1 Trigger Pipeline

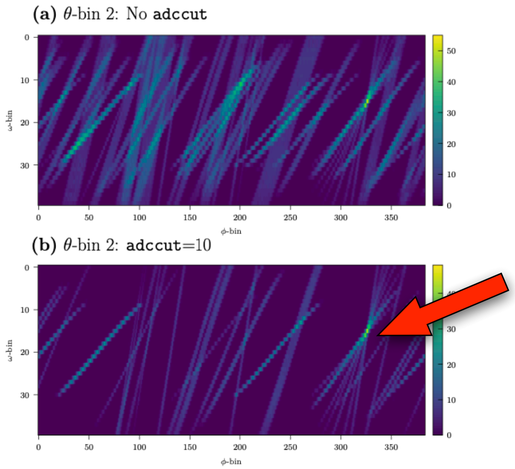


- Neuro Tracker/ DNN Tracker latency: from 300ns to 700ns window

Neuro Tracker

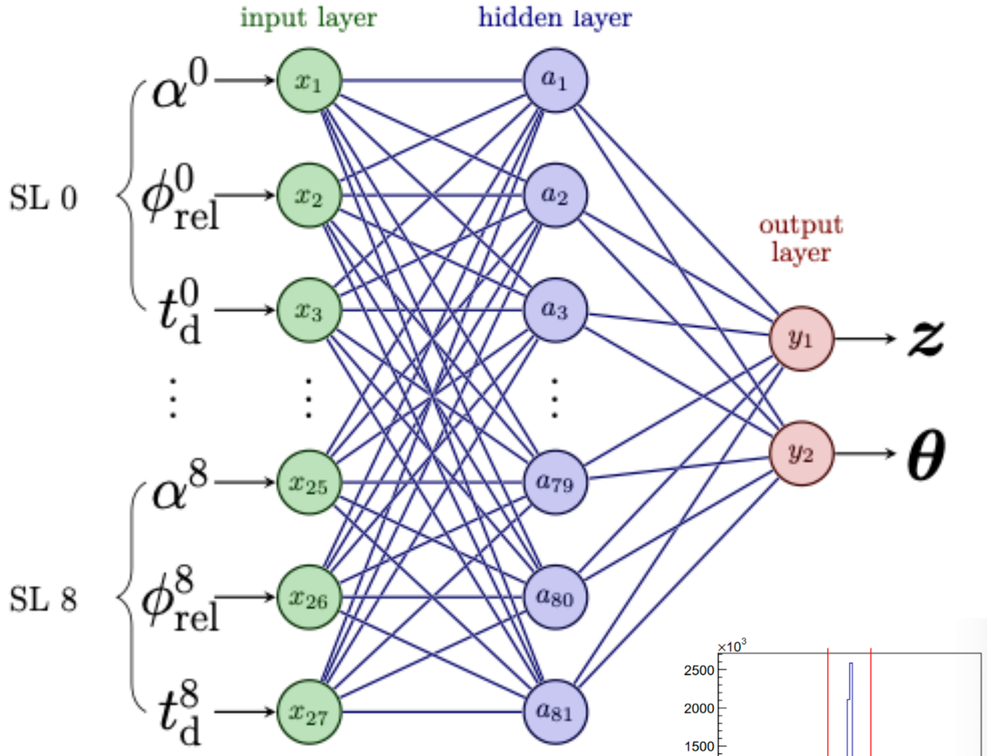
- z and θ prediction by NN → cut at z = ±15cm
- features α, ϕ, t_d from (2D) Hough transform
- only 1 hidden layer due to latency constraints
- Problem: high backgrounds (many fake tracks, feed down effect)
  → introduce ADC cut



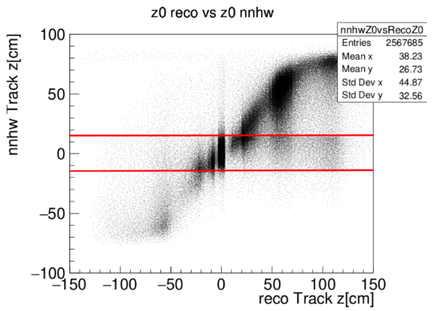


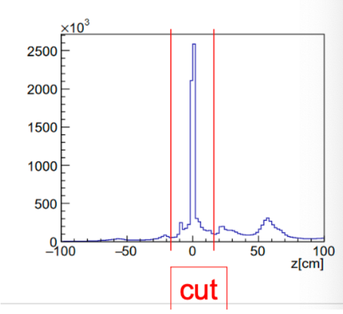
only true track („fan out“)

⟹ Reduction of noise using a cut on the ADC count



$\Longrightarrow$ z-cut of $\pm 15\,\text{cm}$ used



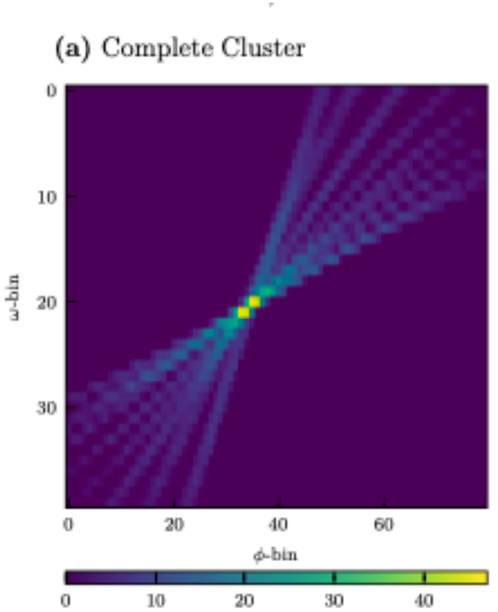


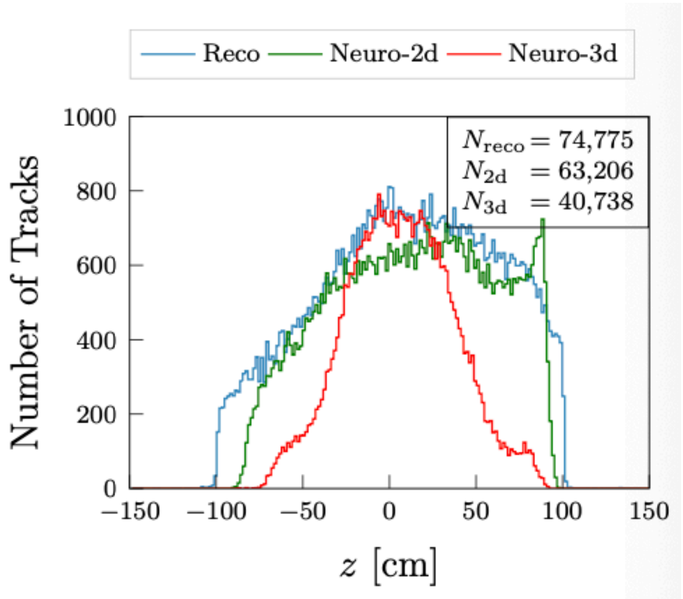
02.10.2024 Greta Heine - greta.heine@kit.edu

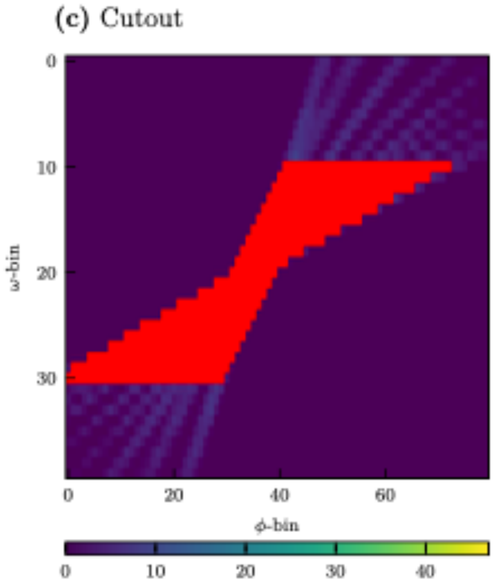
3D Finder

- 3D (Hough space) by adding polar angle θ (Hough plane → Hough curve)
- IP assumption (0,0,0) → automatic suppression of tracks outside the interaction region)

- Fixed volume clustering
  - 1) global maximum search on Hough space
  - 2) fixed shape around maximum and saved if weights high enough
  - 3) remove these cells (butterfly-shape cutout)
  - 4) repeat
- ⇒ better z resolution than 2D Finder
- ⇒ higher efficiency, smaller fake rate







Intersection point yields ω, ϕ and θ

02.10.2024 Greta Heine - greta.heine@kit.edu

Optimized Inputs for the Neuro-Track-Trigger and Principles for a Displaced Vertex-Trigger

Timo Forsthofer, Christian Kiesling, Kai Unger, Simon Hiesl

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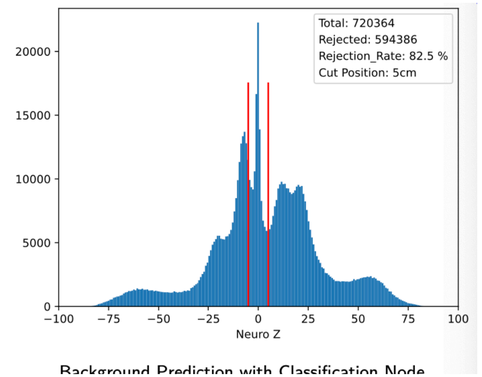
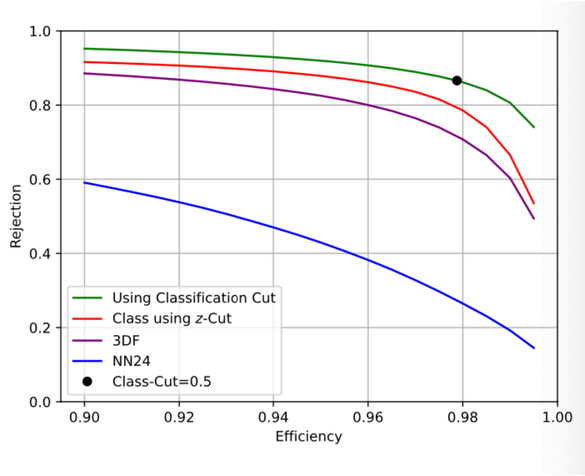
Extended Inputs and DNN

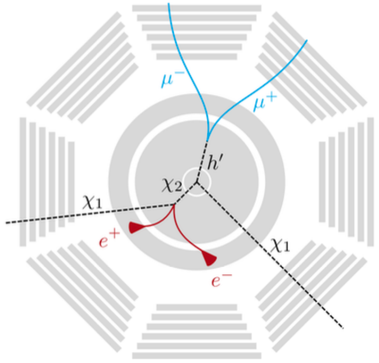
- use of all TS wires (axial and stereo)
- 3 hidden layers instead of 1 → improve resolution → reduce z cut to ± 10cm for better rejection rate
- deeper NN is better than wider (working point 4x60 nodes)
- better efficiency and fake rate with ADC cut at 10
- reduced drift time resolution (-1 if missed, 1 above ADC cut, 0 below) without performance loss
- extra z output node: better background rejection at IP (+5%) with third output node trained on binary $|z_{reco}| > 1$cm instead of „just“ z-cut

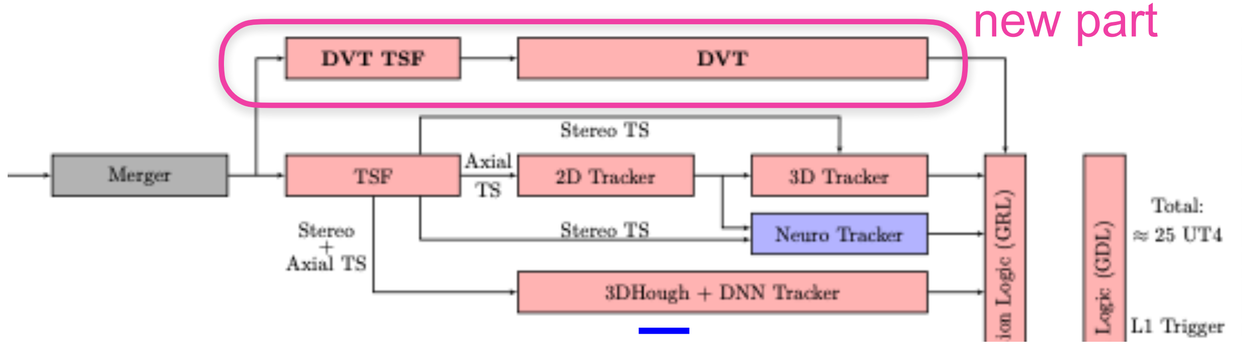
For z-Cut at 15cm, Rejection Rates are 39.5% (NN24), 44.0% (DNN) and 50.6% (XI), with Efficiencies at 95.7% (NN24), 97.0% (DNN) and 98.2% (XI)



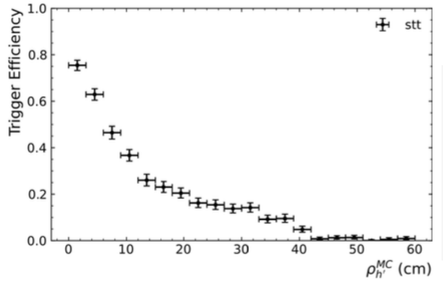


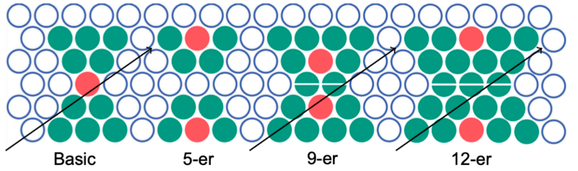
Displaced Vertex Trigger



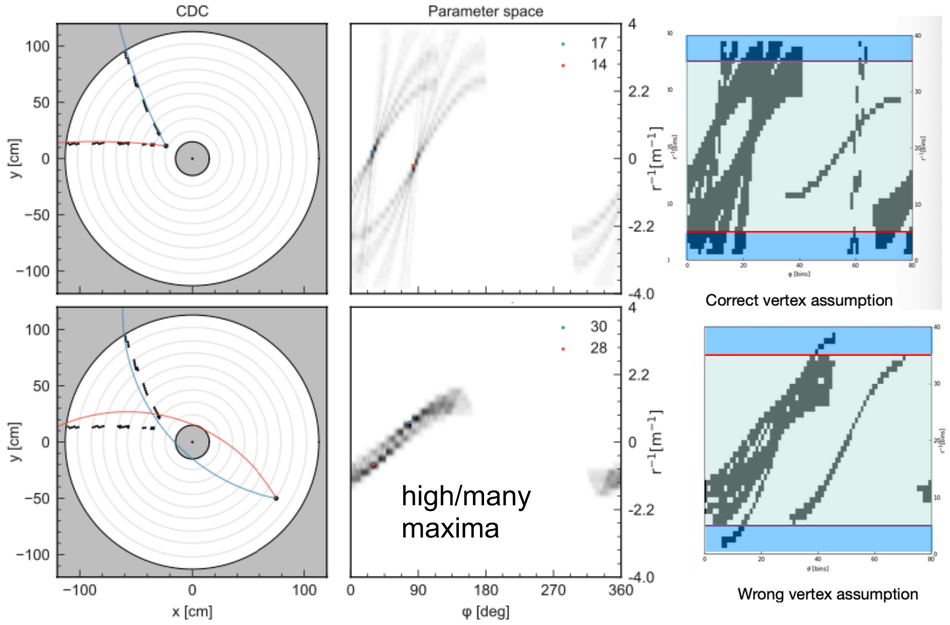


- current TRG restricted on tracks from IP
- introduce new LUT based track segment patterns
- parallel Hough transform for every vertex assumption (on 100 MacroCells)





- wrong assumptions have high maxima, but different shape
- instead of maxima calculate ratio of small radii/high radii in bitmap
- only take 5 highest scores
- add neighbours iteratively to maxima (max 5 iterations)



- store 10 cluster parameters, track curvature and 2D opening angle to DNN
- small NN with high output cut due to high BG rate

- not implemented yet

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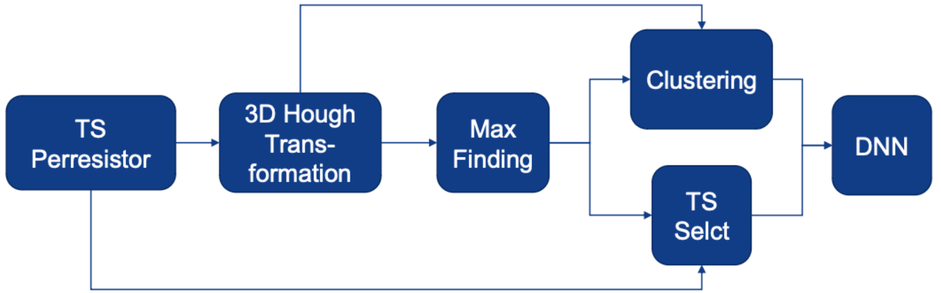
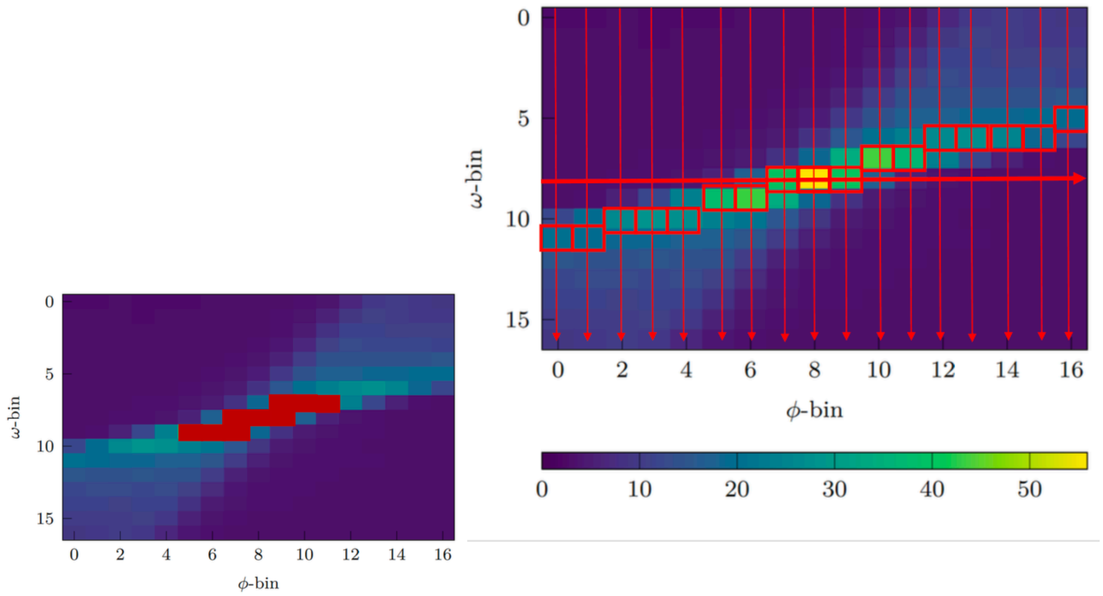
3D Hough Hardware Trigger Implementation

Kai Unger

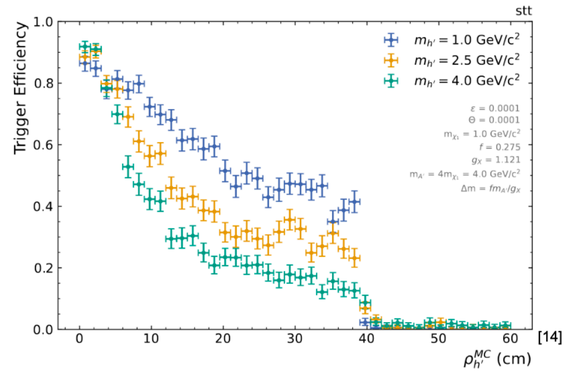


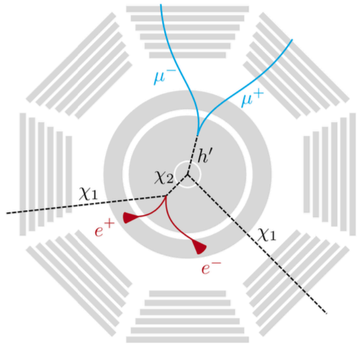
- replace 2D Finder and z-vertex Track Trigger by **3D Hough** (1 µs latency)
  - more latency for Neuro Tracker/ DNN
  - better z-resolution and polar scattering angle θ
- 1) 3D Hough plane with curves from look-up tables
- 2) maximum finding in parallel
- 3) fix point clustering (= fixed runtime)
- 4) track segment selection as DNN input (from maximum)



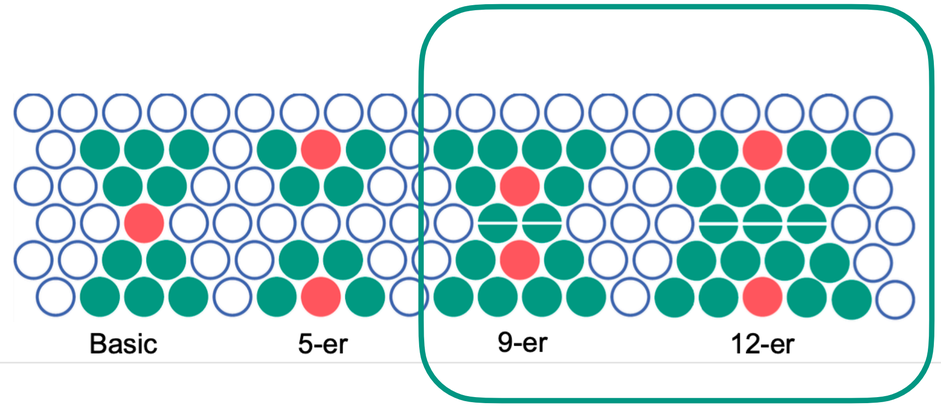
Displaced Vertex Trigger

- new track segment pattern to become sensitive to flat tracks (stored in LUT)
- multi Hough DVT: parallel Hough transformations for different origin hypotheses
- instead of calculating maxima, instead look at radio ratios (parts above and below thresholds)
  - black/ white image → count pixels → up to 12 parallel hypotheses testing per FPGA

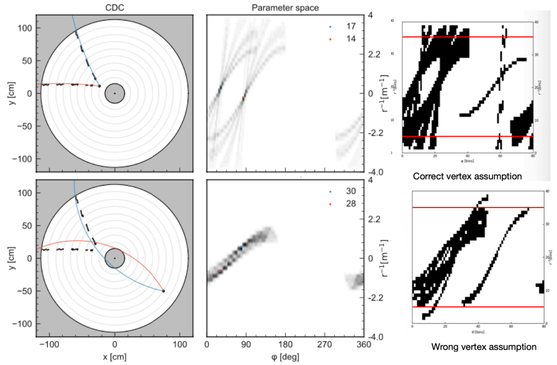




14Patrick Eckler; 2023 Belle II German Meeting



best



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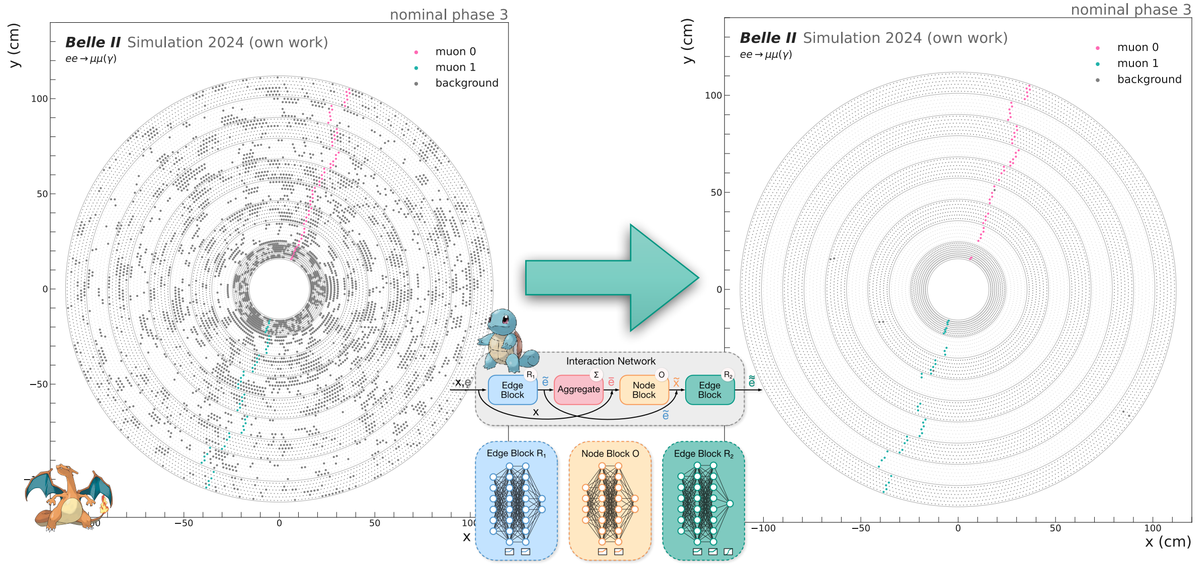
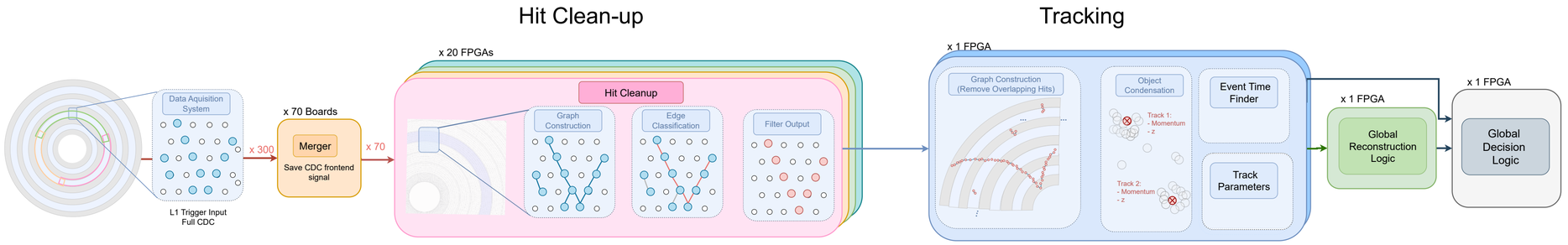
CDC Hit Clean-up for Tracking

Greta Heine, Torben Ferber, Lea Reuter, Slavomira Stefkova, Giacomo De Pietro

- GNN based Hit clean-up with interaction network (small network type)
- based on hit pattern, ADC and TDC
- trained on unbiased sample mix for different backgrounds





Evaluation on simulated $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$

- GNN Hit Clean-up can significantly **improve tracking** (e.g. experiment 0, KKMC muon pairs):
  - track charge fitting efficiency 78.2% → 92.0%
  - track fitting fake rate 6.8% → 2.4%
  - Hit Clean-up significantly reduces the time needed for track finding and track fitting at high backgrounds
  - potential for further time improvement by implementation in C++ instead of Python
- implementation on **L1 TRG level** is planned
  - first studies on L1 TRG conditions are carried out
  - next steps include optimization on L1 TRG conditions and implementation studies

Tracking Modules

Preparation and Hit Cleanup
RegisterEventLevelTrackingInfo
TFCDC_WireHitPreparer
HitCleanup

Track Finding
TFCDC_ClusterPreparer
TFCDC_SegmentFinderFacetAutomaton
TFCDC_AxialTrackFinderLegendre
TFCDC_TrackQualityAsserter
TFCDC_StereoHitFinder
TFCDC_SegmentTrackCombiner
TFCDC_TrackQualityAsserter
TFCDC_TrackQualityEstimator
TFCDC_TrackExporter
IPTrackTimeEstimator
CDCHitBasedT0Extraction
CDCTrackingEventLevelMdstInfoFiller

Track Fitting
SetupGenfitExtrapolation
FullGridChi2TrackTimeExtractor
TrackFinderMCTruthRecoTracks
MCRecoTracksMatcher
IPTrackTimeEstimator
Combined_DAFRecoFitter
TrackCreator

- $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$
- KKMC generator
- 1000 events

nominal-phase 3 

	charge_efficiency*	efficiency*	fake_rate*	clone_rate*	hit_efficiency	total time	time_finding	time_fitting	time_HitCleanup
basf2 only	78.20% +- 1.05%	78.46% +- 1.04%	6.82% +- 0.69%	0.00% +- 0.00%		346.3 +- 154.4 ms/call	195.2 +- 52.5 ms/call	146.3 +- 166.3 ms/call	
best Hit Clean-up model**	↑ 91.96% +- 0.69%	↑ 92.73% +- 0.66%	↑ 2.36% +- 0.39%	↑ 0.00% +- 0.00%	81.72%	↑ 266.6 +- 59.4 ms/call	↑ 21.6 +- 8.9 ms/call	↑ 60.2 +- 56.2 ms/call	179.1 +- 24.6 ms/call

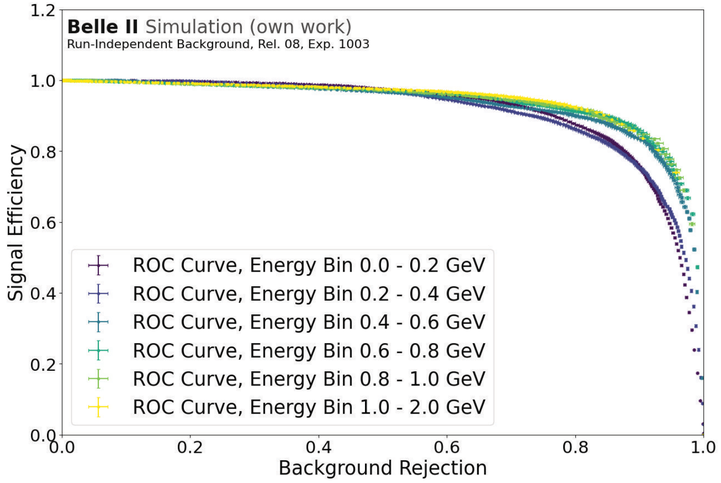
*track fitting metrics **current state of work, more to come, best settings: CDCWireHits, z=0 coordinates, ADC > 9, TDC > 4240 , GNN cut 0.2

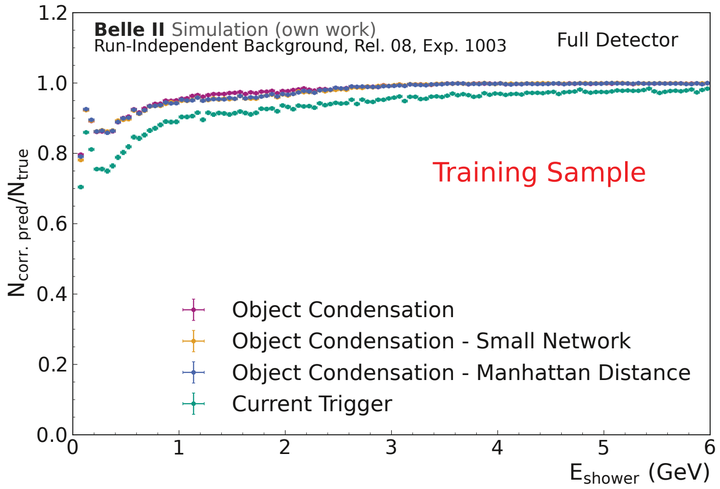
Object Condensation with Graph Neural Networks for the ECL Trigger - Status and Implementation

Isabel Haide, Marc Neu, Timo Justinger, Torben Ferber

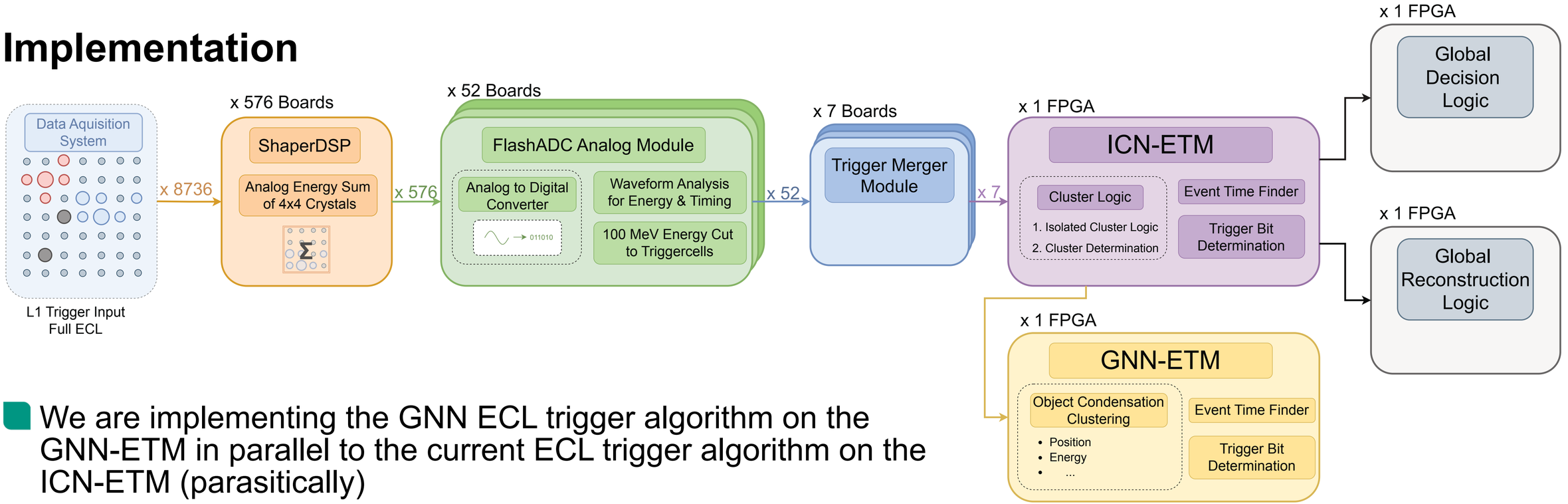
- Current ECL trigger algorithm will have difficulties with higher backgrounds
  → Development of new GNN Trigger algorithm
- Object Condensation algorithm can predict clusters and their properties in one step
- Network can classify signal/background clusters on training data with high efficiency and high beam background rejection
- For optimization for hardware implementation, high reduction of free parameters and replacement of Euclidean distance with Manhattan distance necessary
  → Performance of network stable and outperforming current trigger algorithm

Distance	LUTS	FF	BRAM	DSP
Euclidean	13.79%	9.24%	6.96%	30.64%
Manhattan	14.87%	9.18%	6.96%	1.28%



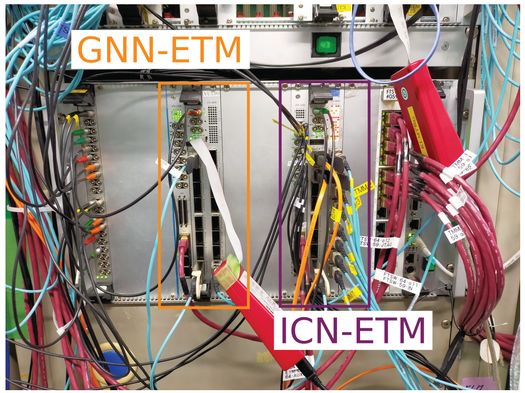


Implementation



- We are implementing the GNN ECL trigger algorithm on the GNN-ETM in parallel to the current ECL trigger algorithm on the ICN-ETM (parasitically)
- Preprocessing, interface between ICN-ETM and GNN-ETM and Belle2Link DAQ is already done
- Algorithm will store predicted clusters and their properties in raw data but will not be involved in trigger decisions

  ⇒ Starting to run this in two weeks!



News from the Onsen PXD readout system

Dmytro Meleshko

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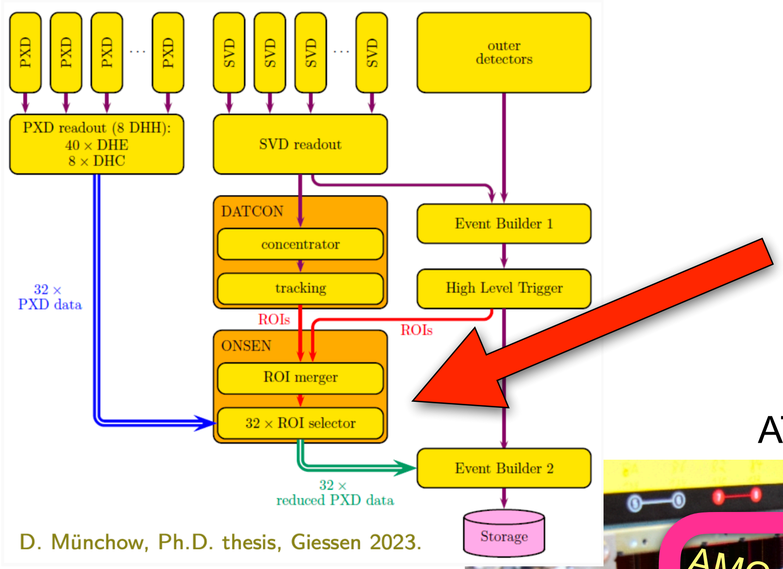
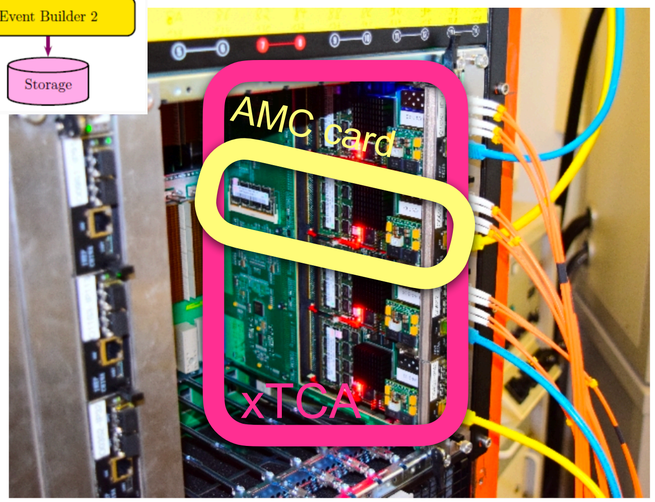
- PXD data (~10x more data than rest of Belle II) stored for HLT decision
- data reduction by factor >10 by ROI selection on HLT (online tracking)
- **hardware solution:**
  - ATCA shelf with 14 slots (8 for Onsen)
  - xTCA carrier card carrying 4 AMC cards (Virtex-5 FPGAs)
  - hardware not manufactured anymore, spare parts are available but not abundant (only 1 spare carrier board)
  - ⇒ development of new generation by M. Krein



ATCA shelf



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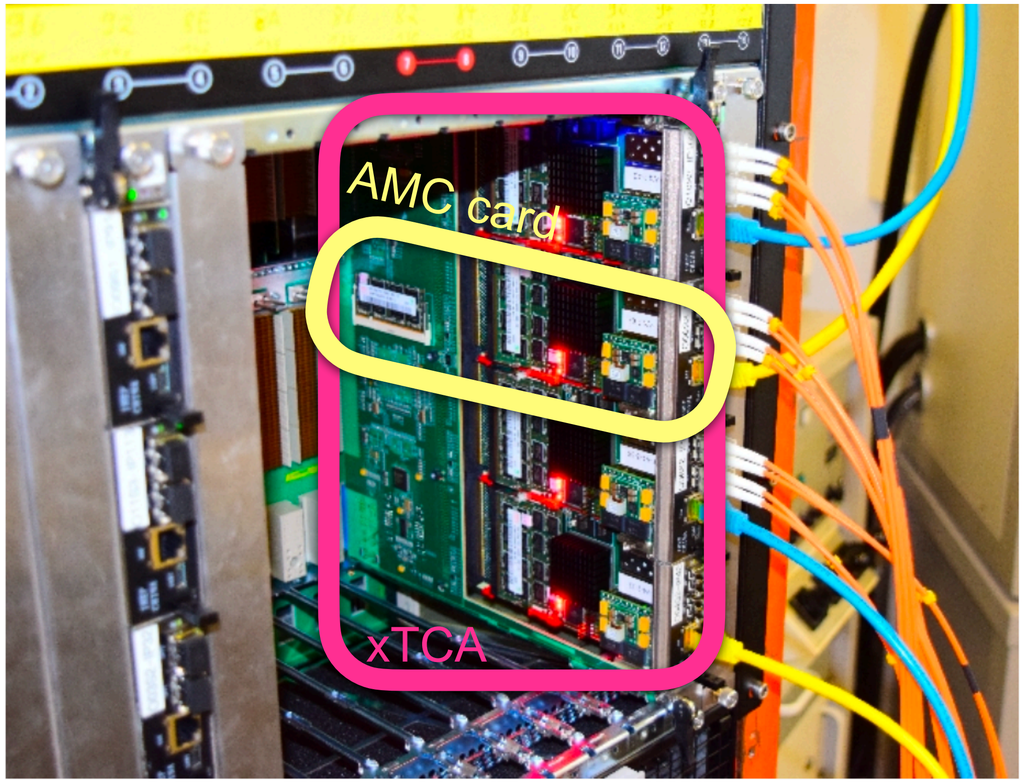
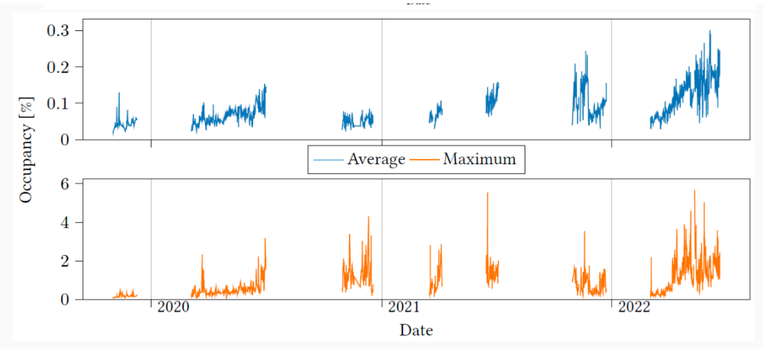


Performance

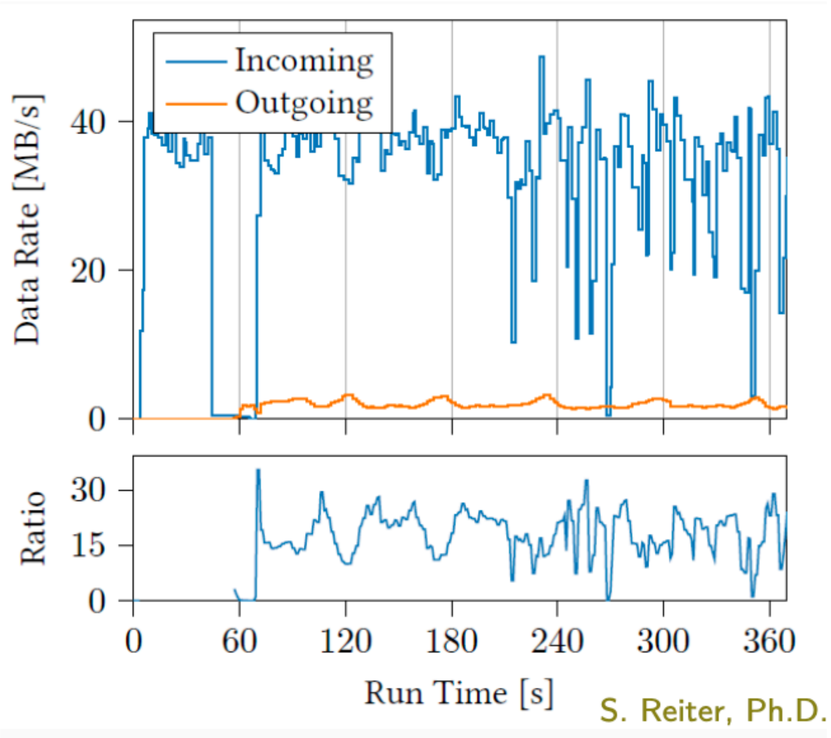
- ONSEN operation has proven overall stability in Run1, stable running in Run2 until PXD2 was switched off;
- Run 1: 300TB zero-suppressed data, TRG rate up to 8kHz (design 30kHz), peak luminosity 3.7 x $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 4 carrier boards
- Run 2: x1.5 dataflow, 8 carrier boards
- occupancy far away from design limits



- event filtering by HLT, 4.41 average reduction factor in phase 3
- ROI filtering by SVD track extrapolation → 20-30 factor (combined) suppression
- **but**, ROI selection forecast is tricky („like Hamburg weather forecast“) scale factor approximation:

$$S = S_{\mathrm{PXD2}} \times S_{\mathrm{HLT}} = 1.84 \times 1.86 = 3.42$$

- ROI selection must be enabled, when Link from ONSEN to Event Builder reaches 1000 MB/s. 2026-2027? (depends on luminosity extrapolation of SuperKEKB)

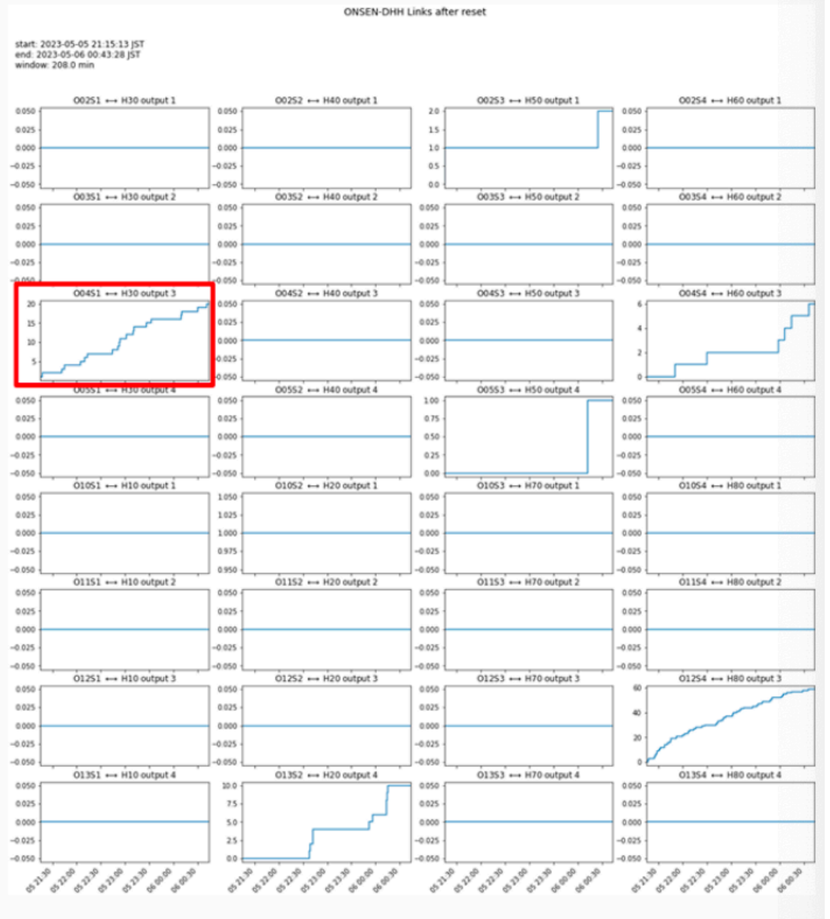


Link stability problems

- Link stability challenges have risen after LS1:
  - Not critical for operation
  - Search for solutions is ongoing
  - Observed persistently for one link only
  - several AMC swaps suggest that the issue is not on the ONSEN side
  - → go from 6 Gbps to 3 Gbps for now
  - The upcoming hardware upgrade of the adjacent DAQ components will trigger further tests

There are two types of link problems:

- Link drops (rare, 1 per day, but crashes DAQ)
- Link errors (not fatal, but worrisome)



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Thank you all
for the nice discussions!

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