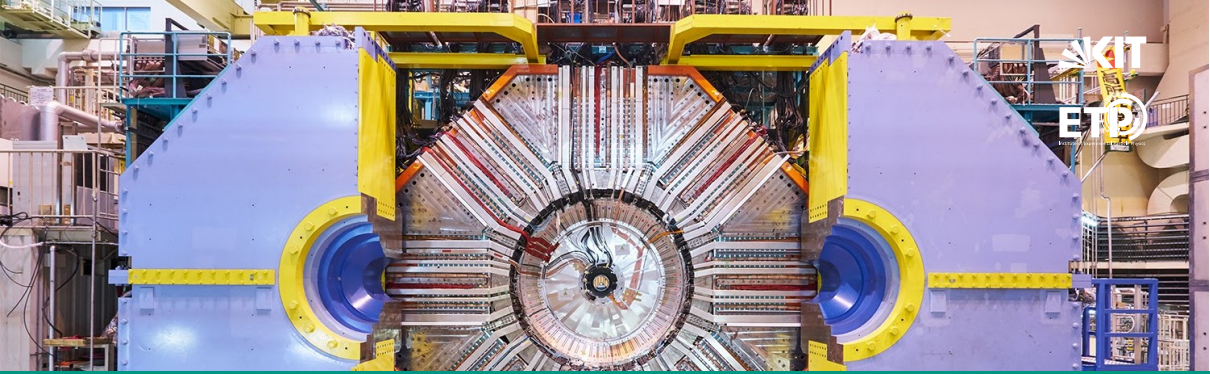

ECLTRG Logic Upgrade

TRG-DAQ Workshop, 23. October 2025

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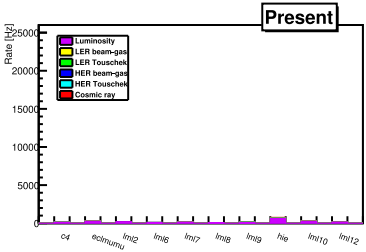
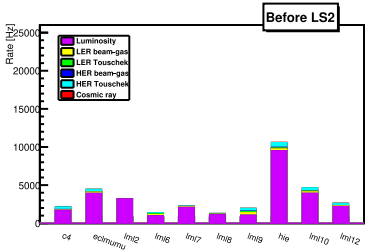
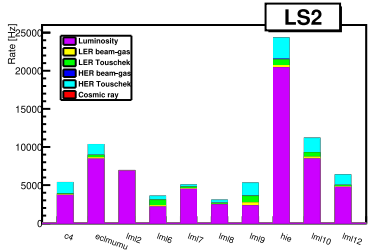
Trigger Rates in Future Conditions

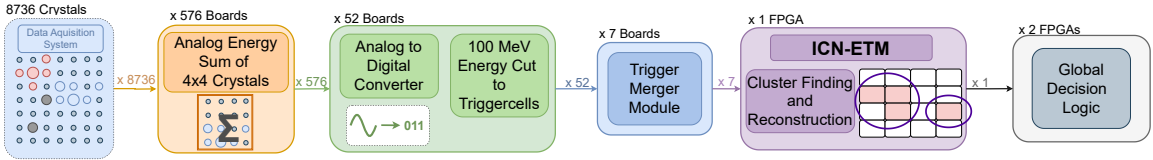
- Trigger rate extrapolations based on dedicated beam time studies (Belle II Note) show significantly increased rates of ECL trigger bits with higher beam currents and higher luminosities. Luminosity background is the highest contribution for the ECL trigger.
- Loose trigger bits such as `hie` are used by many analyses and will have to be prescaled in future conditions to keep within the DAQ limit.
- Improved readout strategies and new clustering algorithms have to be employed to keep a high trigger efficiency for all analyses.







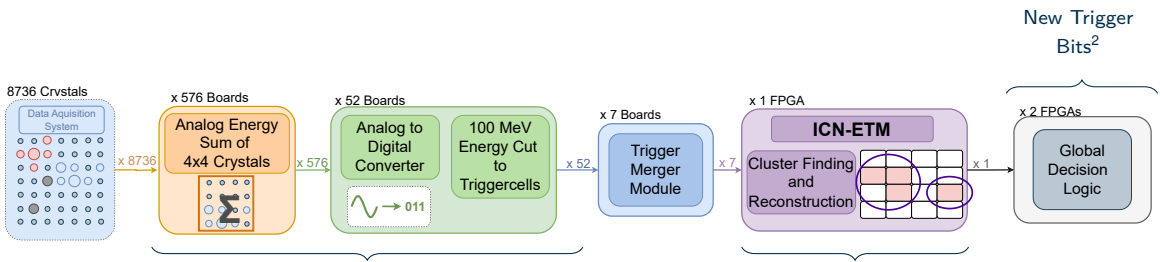
The Current ECL Trigger: ICN-ETM



Current Challenges:

- Coarse granularity of input results in limited position resolution, no resolution for overlapping clusters.
- Coarse granularity of input does not preserve shower shape information.
- ICN-ETM can only return up to 6 clusters per event.
- Loose trigger bits have to be prescaled to reduce overall trigger rate with higher luminosity, leading to a loss in efficiency for analyses. Trigger bits such as c2 (two clusters or more in the inner ECL) are already turned off.

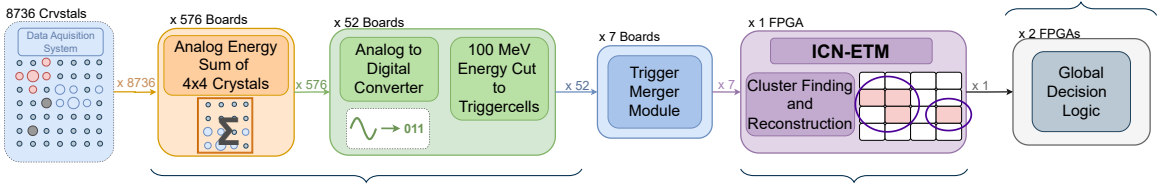
Improvement Possibilities after LS2



[1] GNNETM running in 2025c (paper in preparation, Presentation at FastML)

[2] TauNN (Presentation at FastML)

Improvement Possibilities after LS2



Increase granularity, improve feature extraction (ShaperDSP upgrade)
Change energy cut/crystal selection
(ML/Conventional algorithms for further filtering)

New clustering algorithms[1] with increased latency budget

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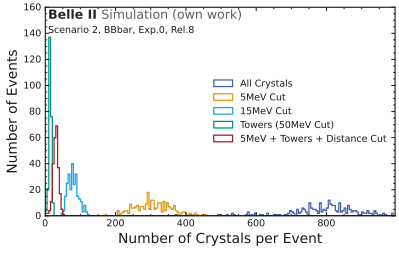
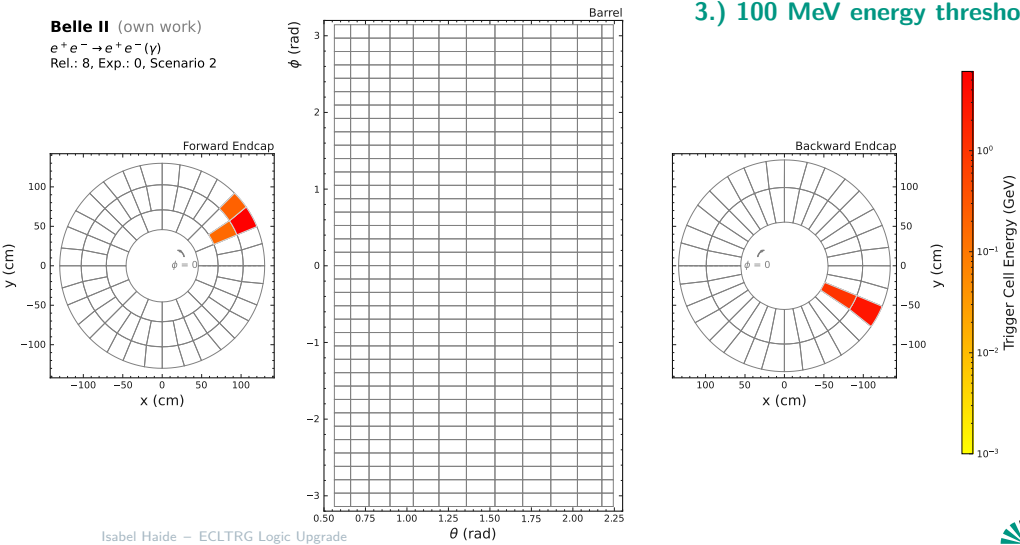
Improvements toward Upgrade - Input Possibilities

- ECLTRG input can be upgraded from 4x4 TCs to crystals with ShaperDSP upgrade. However, all active crystals ($\approx$ 800 per event) as input is too much for even very modern hardware (Versal/AI Engines) with our current algorithms.
- We test two (so far purely theoretical) reduction possibilities to reduce the input to <128:
  1. Flat energy cut for all crystals, which is similar to current handling of TCs.
  2. Selection of so-called trigger towers:
     a. Find high energetic crystals, e.g. crystals above 50 MeV.
     b. Select these crystals and a "tower" around it, all active crystals in a 5x5 area, if necessary with additional energy cut.
- One other possibility would be segmentation of ECL and processing on multiple FPGAs.



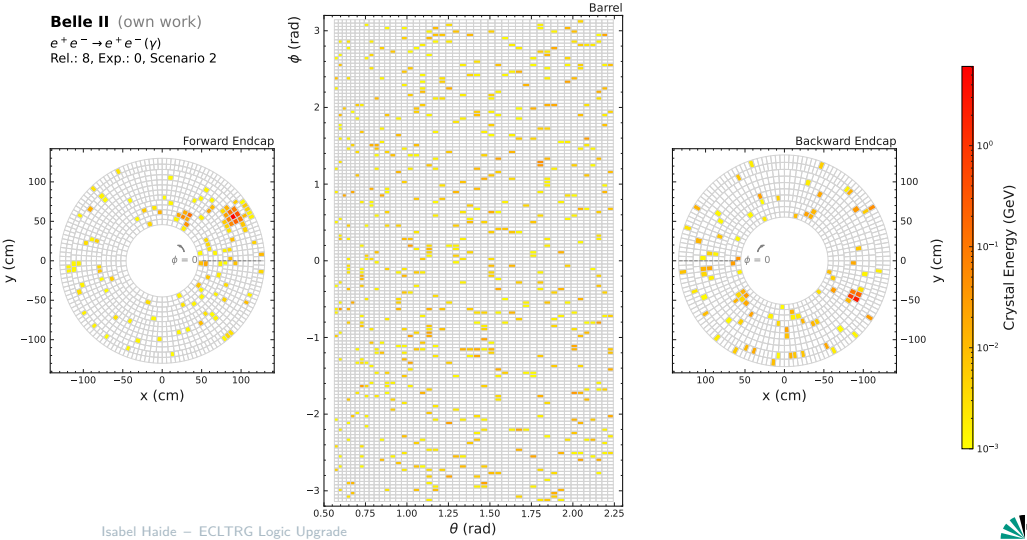
4x4 TC Event Display

1.) Timing window of 250 ns
2.) 4x4 energy sum
3.) 100 MeV energy threshold



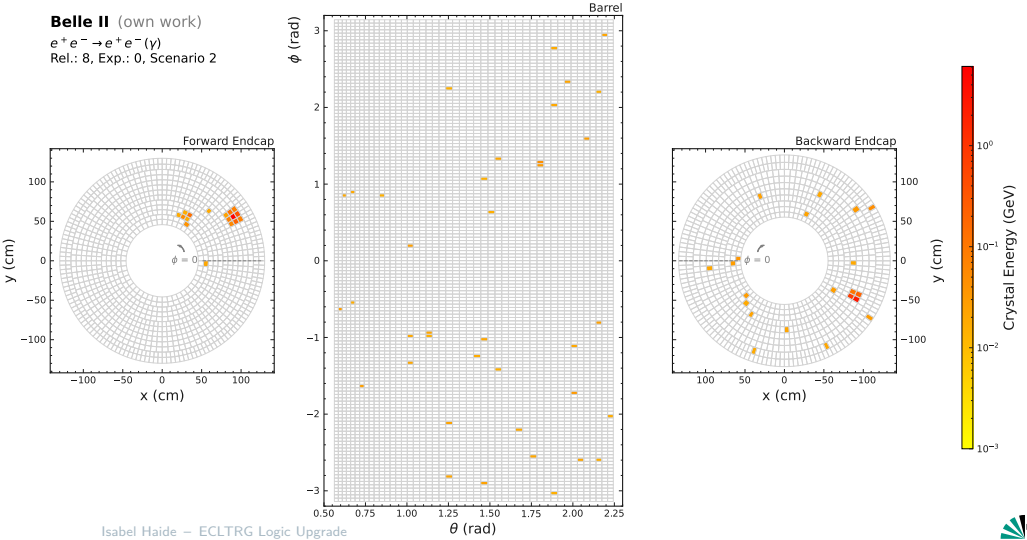
1x1 TC Event Display

1.) Timing window of 250 ns



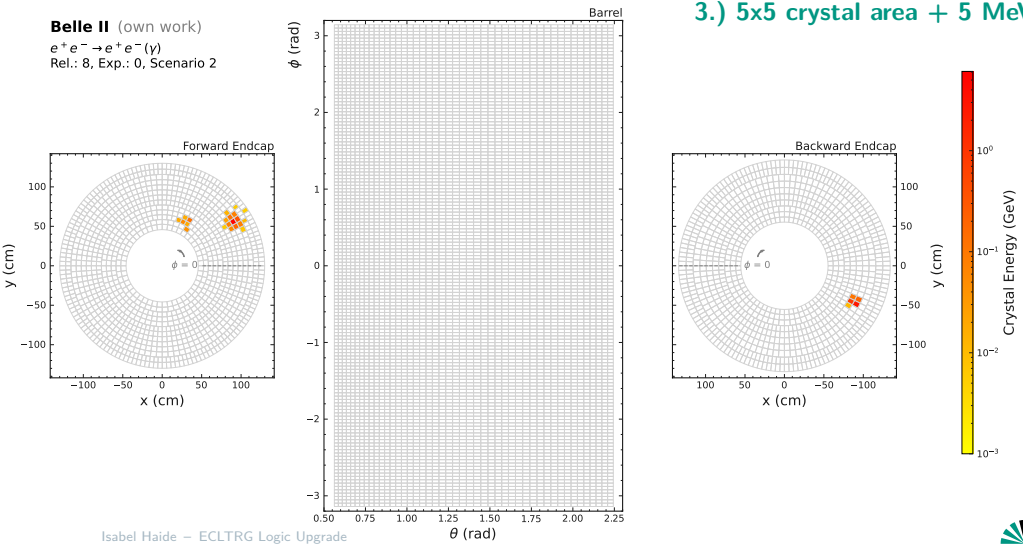
1x1 TC - Flat Energy Cut

1.) Timing window of 250 ns
2.) 15 MeV energy threshold



1x1 TC - Trigger Towers

1.) Timing window of 250 ns
2.) 50 MeV high energy cut
3.) 5x5 crystal area + 5 MeV cut



Improvement Possibilities after LS2

Increase granularity, improve feature extraction (ShaperDSP upgrade)
Change energy cut/crystal selection
(ML/Conventional algorithms for further filtering)

New clustering algorithms[1] with increased latency budget

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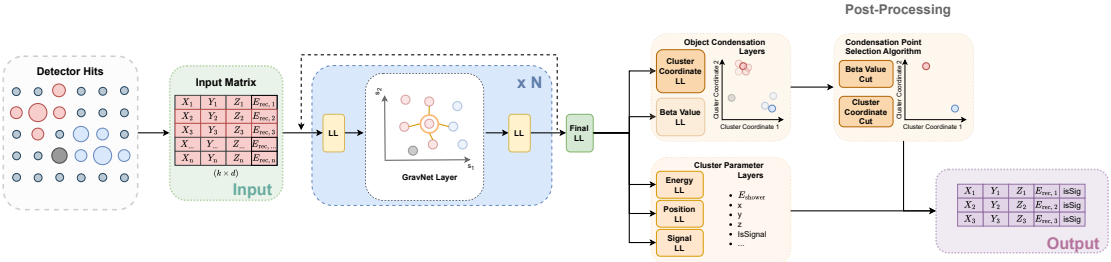
Improvement Possibilities - Clustering Algorithm



- We need a working algorithm to process and cluster 1x1 crystals within the restrictions of the post-LS2 trigger system ($\approx$ 8 MHz throughput, 10 μs latency).
- GravNet architecture has proven to work well for clustering algorithms in the ECL for both offline[1] and online[2] applications.
- We use the same architecture as for the GNN-ETM model, but applying it to single crystals with flat energy cut/trigger tower selection.

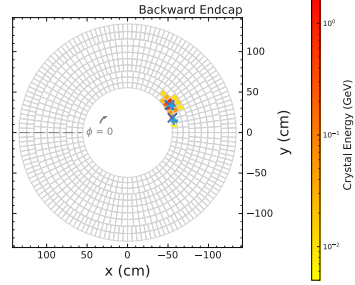
[1] Photon Reconstruction in the Belle II Calorimeter Using Graph Neural Networks, F. Wemmer et al. (Paper)

[2] GNNETM (paper in preparation, Presentation at FastML)

Clustering Algorithm - Proof of Concept

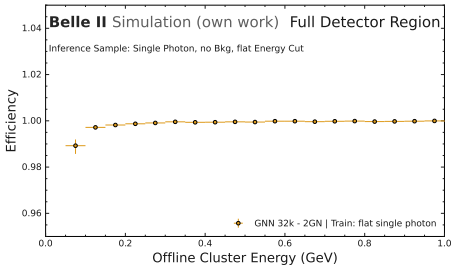
T. Lobmaier

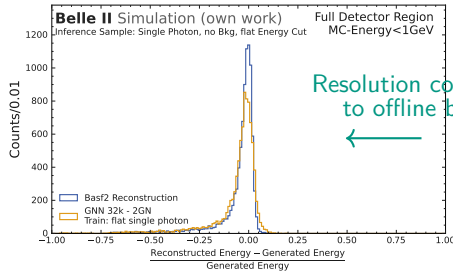
+ GNN Prediction
× Offline Clusters



- First trained models on very simplified datasets (no/low beam background, particle gun photons) show promising performance.
- Model is not optimized for hardware implementation, but has low number of parameters (<5000).
- We are moving towards more realistic scenarios and testing the different input reduction possibilities.

Single Photons, no beam background

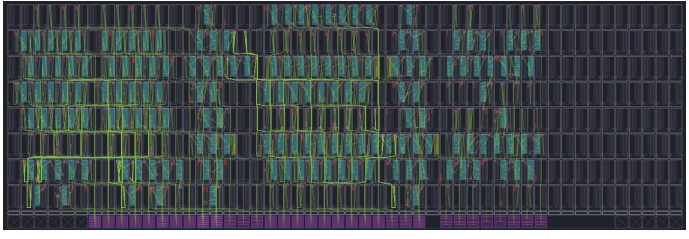




Resolution compared to offline basf2

Clustering Algorithm - Implementation

- We test the GNN network with a maximum of 128 inputs on an AMD Versal VCK190 Board, featuring a XCVC1902 with 400 AI Engines. The high number of inputs is very challenging even for this hardware, we use a hybrid implementation with both AI Engines and the programmable logic.
- The first full, successful implementation reaches a latency of $\approx 10\ \mu s$.
- The programmable logic is running at $f_{sys} = 256$ MHz, the total throughput is at ≈ 1 MHz. A new tiling concept for the AIEs could increase the throughput up to 4 MHz by reducing memory stalls.



	HLS Part	AIE Part
LUT	55.74 %	0 %
FF	25.37 %	0 %
DSP	17.07 %	0 %
BRAM	67.43 %	0 %
AIE tiles for calculations	0 %	40 %
Total used AIE tiles	0 %	66.75 %

Summary and Outlook

- New readout possibilities due to ShaperDSP upgrade increase granularity and allow use of shower shape information, but necessitate the design of new algorithms.
- Additionally, higher luminosity requires new ECL clustering algorithms to avoid prescaling of trigger bits.
- Readout of all crystals not possible to process with our algorithms on our current hardware $\rightarrow$ Reduction of input size with flat energy cut or trigger tower implementation
  – Which is possible on the hardware? Could the trigger towers be implemented?
- We show a first proof of concept ML algorithm for a one-step clustering, which on very simplified events can provide a good efficiency and resolution.
- We implement the model design on an AMD Versal VCK190 Board with an XCVC1902, reaching a latency of 10 μs. To reach the necessary throughput for the Belle II trigger post-LS2, further optimizations are necessary.