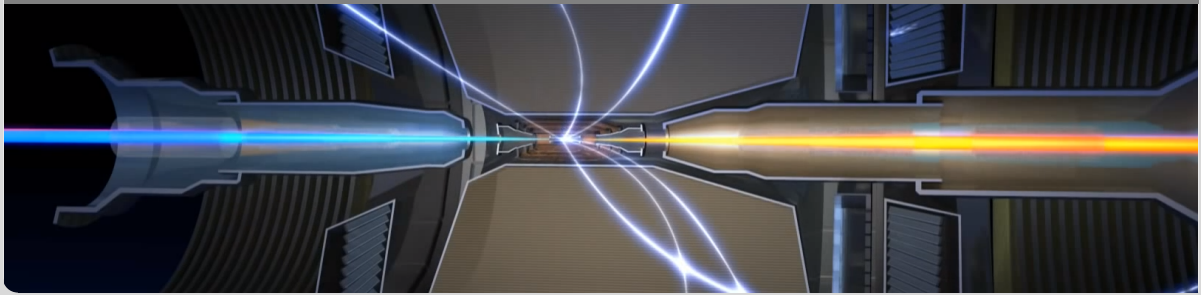
Improving ECL Clustering on Trigger Level with Object Condensation

Belle II Germany Meeting - Parallel Sessions: Software and Computing

Isabel Haide, Torben Ferber | September 20, 2022

INSTITUTE OF EXPERIMENTAL PARTICLE PHYSICS (ETP)



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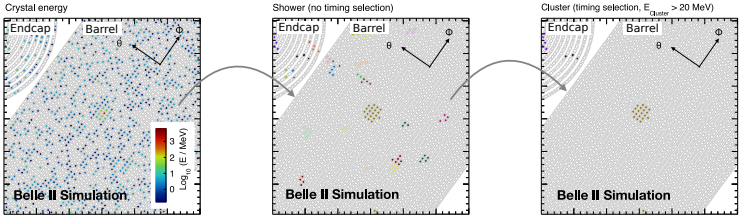
  1. During online reconstruction for L1 trigger decisions
  2. During offline reconstruction for physics analyses



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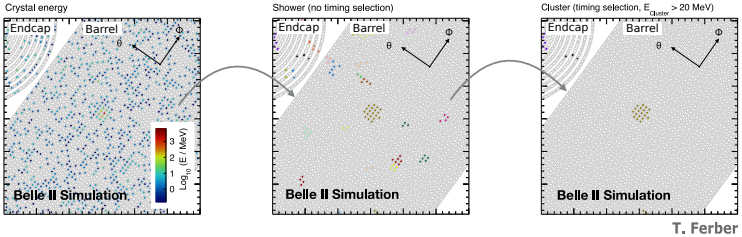

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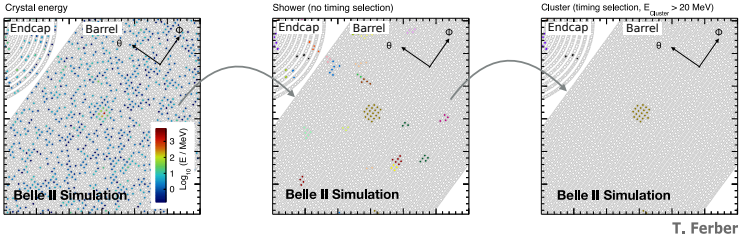

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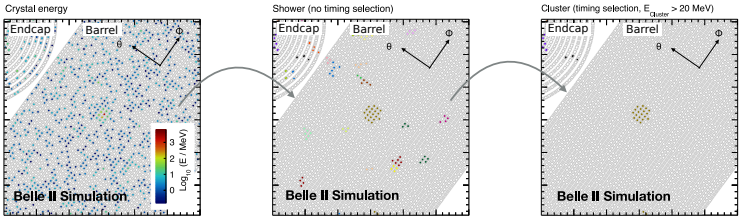
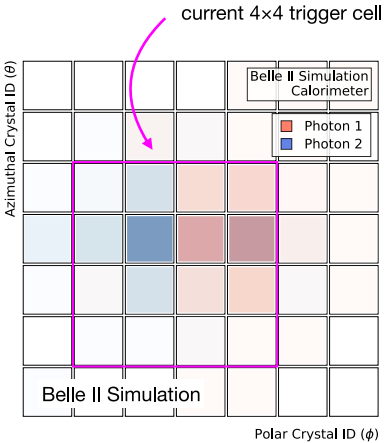
     ⇒ Next talk by Florian Wemmer
- Machine learning algorithms may improve both use cases



Online Reconstruction

- Current L1 Trigger Reconstruction:
  - Decision time $\leq$ 1 µs for ECL, 5 µs total
  - Clusters are reconstructed in trigger cells, possible upgrade would read out more crystals
  - Events with signatures similar to background are filtered
    $\Rightarrow$ loss of potential dark sector signatures, e.g. Dark Photon decay



B. von Krosigk, T. Ferber

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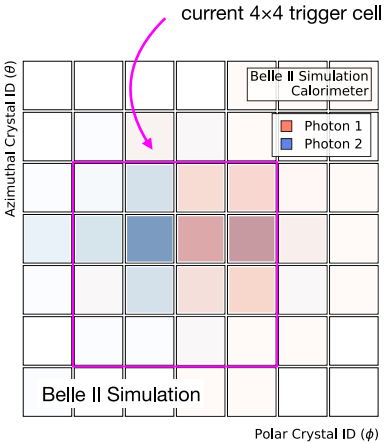
- Use of Machine Learning Algorithms:
  - Graph Neural Networks may provide improvement on real-time clustering
  - Implementation of trained ML model on FPGAs for fast reconstruction
  - Possible better reconstruction of background-like events



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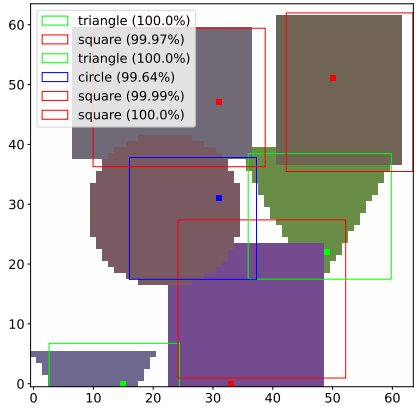
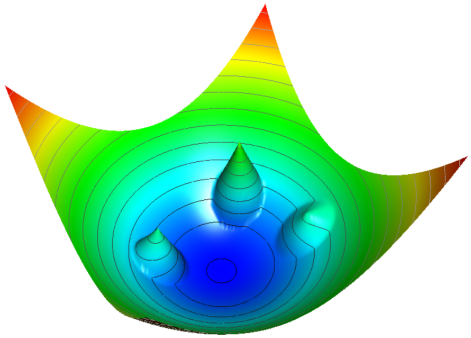
Object Condensation



Input image containing different shapes are overlapped with their predicted condensation points.

- Object condensation (OC) for multi-particle reconstruction by Jan Kieseler (arXiv:2002.03605)
- Objects and their defining properties are condensed into one representative condensation point
- Applicable to overlapping objects without clear spatial boundaries
- No assumptions on the object size or the sorting is needed

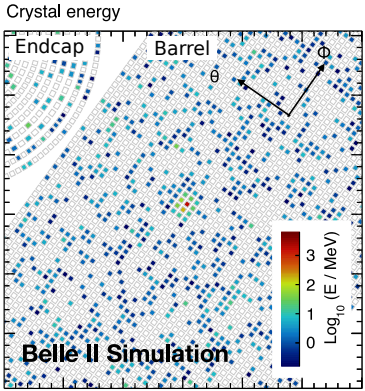
Effective Potential



Effective potential affecting a vertex belonging to the condensation point in the centre. arXiv:2002.03605

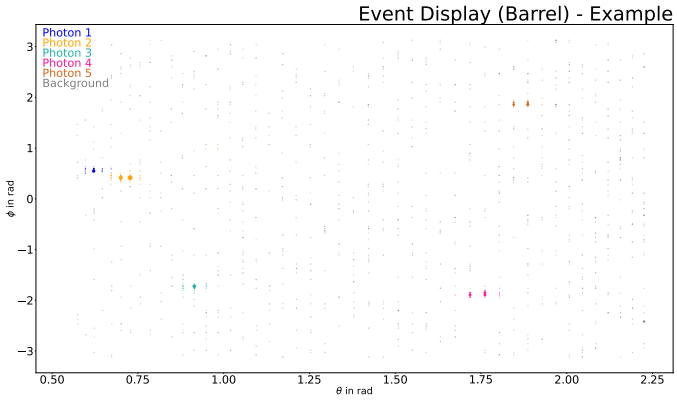
- Effective potential draws vertices to condensation point
- Vertices belonging to the same object are drawn towards the condensation point with the highest charge
- Vertices not belonging to the object are pushed away
- Hyperparameter can tune focus on separation or focus on property prediction

Object Condensation on Belle II Calorimeter Data



- Currently only the barrel region is considered, simulation with release-06-00-03
- Simulation of 1-6 photons per event with energy between 0.05 and 2.0 GeV, with early phase 3 background
- Photons have to deposit $\geq$ 30 % of their energy and more than 10 MeV inside the ECL
- Crystals “belong” to a photon, if at least 50% of the crystal’s energy was deposited by the photon

Object Condensation on Belle II ECL Simulation



- Every crystal with energy deposit $\geq$ 1 MeV is used as input to the network
- Input features are reconstructed energy, reconstructed time and x, y, and z position of the crystal
- Network consists of six blocks with three dense layers, one GravNet layer, and 128 output filters
- Current comparison is against basf2 offline reconstruction, L1 Trigger reconstruction significantly worse

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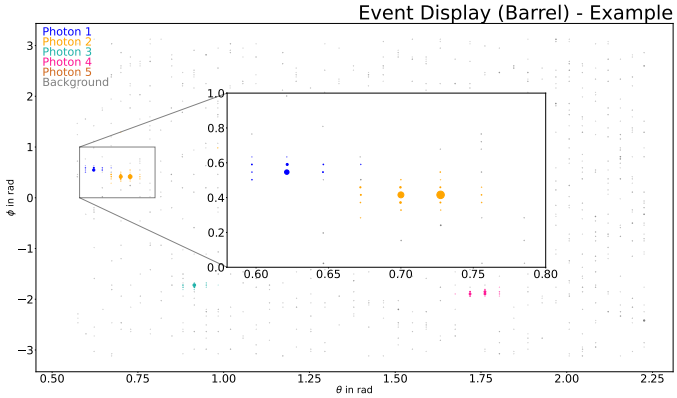

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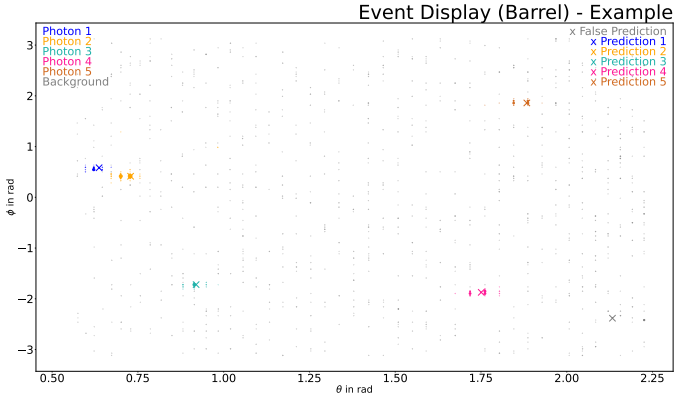
Cluster Prediction by OC and basf2



- OC predicts existence, position (in x, y, and z) and energy
- Predicted positions are shown with x
- Predictions are matched to true cluster, false predictions are shown in grey

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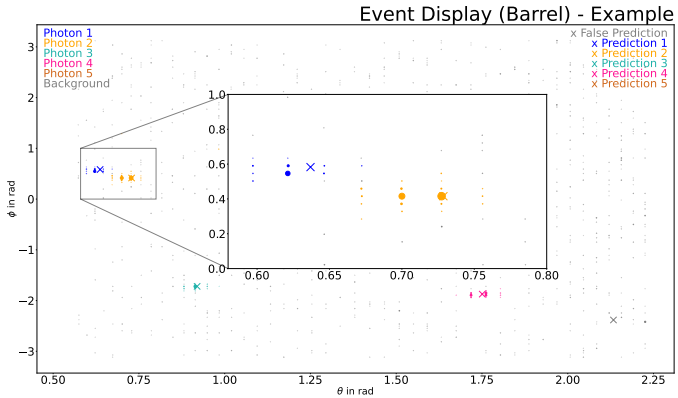

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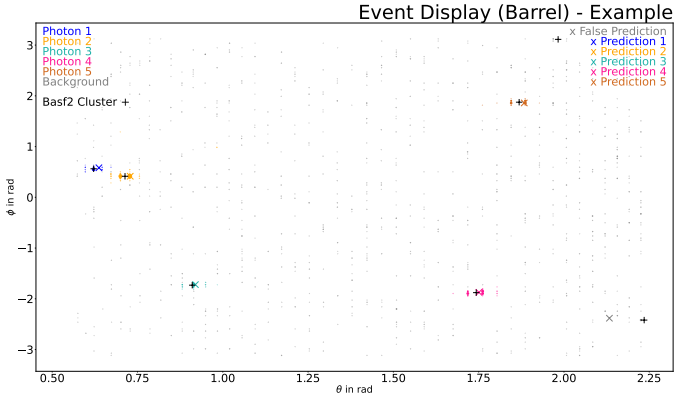

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- basf2 also predicts existence, energy, and position
- Reconstruction by basf2 needs local maximum to reconstruct cluster, not necessarily existent here

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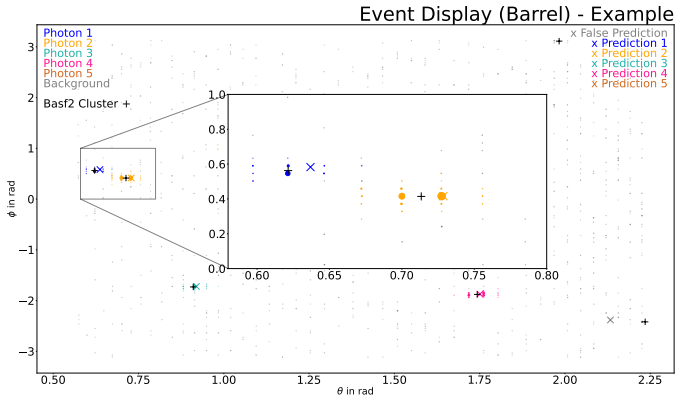

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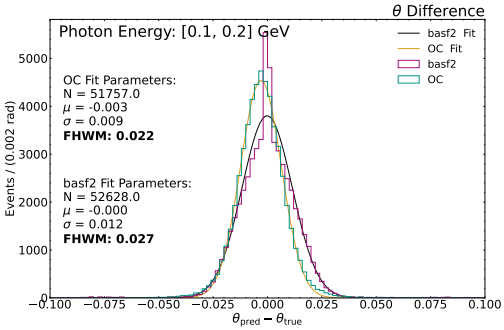
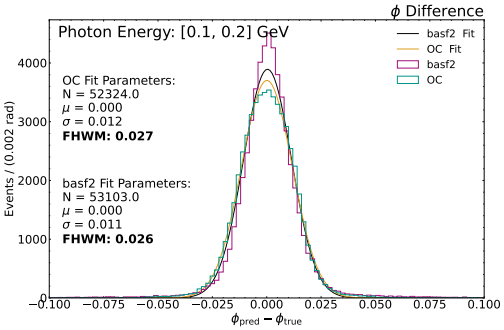
θ and ϕ Resolution

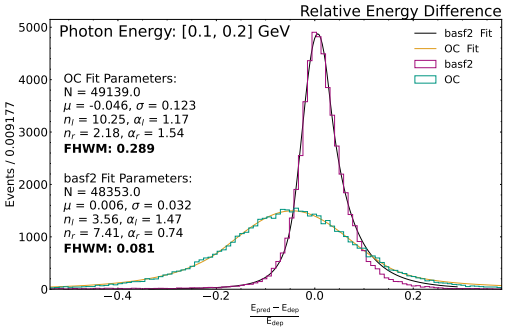


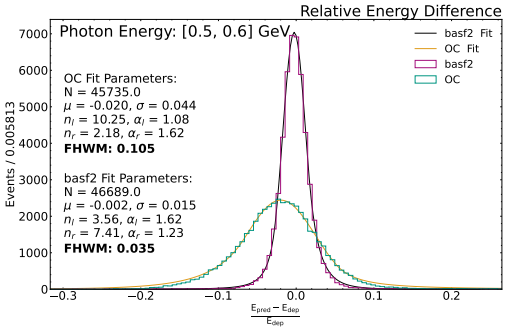


Position resolution for correctly predicted photons

- Similar position error of OC and basf2, resolution improves with higher energy
- θ and ϕ resolution does not differ significantly

Energy Resolution

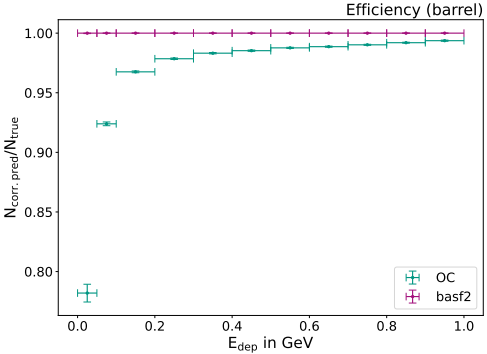


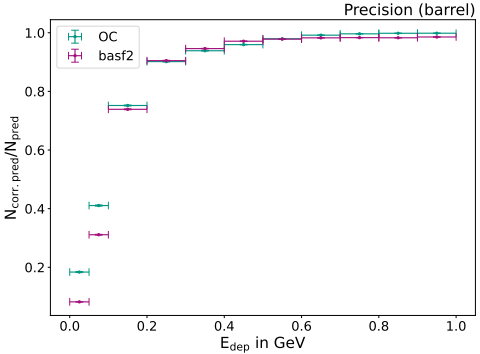


Energy resolution for correctly predicted photons

- Energy resolution improves with higher energy for both basf2 and OC
- Basf2 is still significantly better than OC

Efficiency and Precision





Efficiency and Precision for all photons

- Basf2 tends to overestimate the number of photons, while OC underestimates the number of photons
- Errors are higher for lower energy photons

Summary

Object Condensation as a clustering algorithm

- OC can predict cluster existence, position and energy simultaneously
- Energy resolution and efficiency of basf2 still outperforms OC
  $\Rightarrow$ Improvements through tuned network architectures and optimized trainings

Further steps

- Extending to full ECL and Phase 3 Background
- Including hadronic and non-photon clusters
- Decreasing network size for implementation on FPGA

Missed Cluster