Karlsruhe Institute of Technology

Institut für Experimentelle Teilchenphysik

(Fast) Machine Learning for Belle II at ETP

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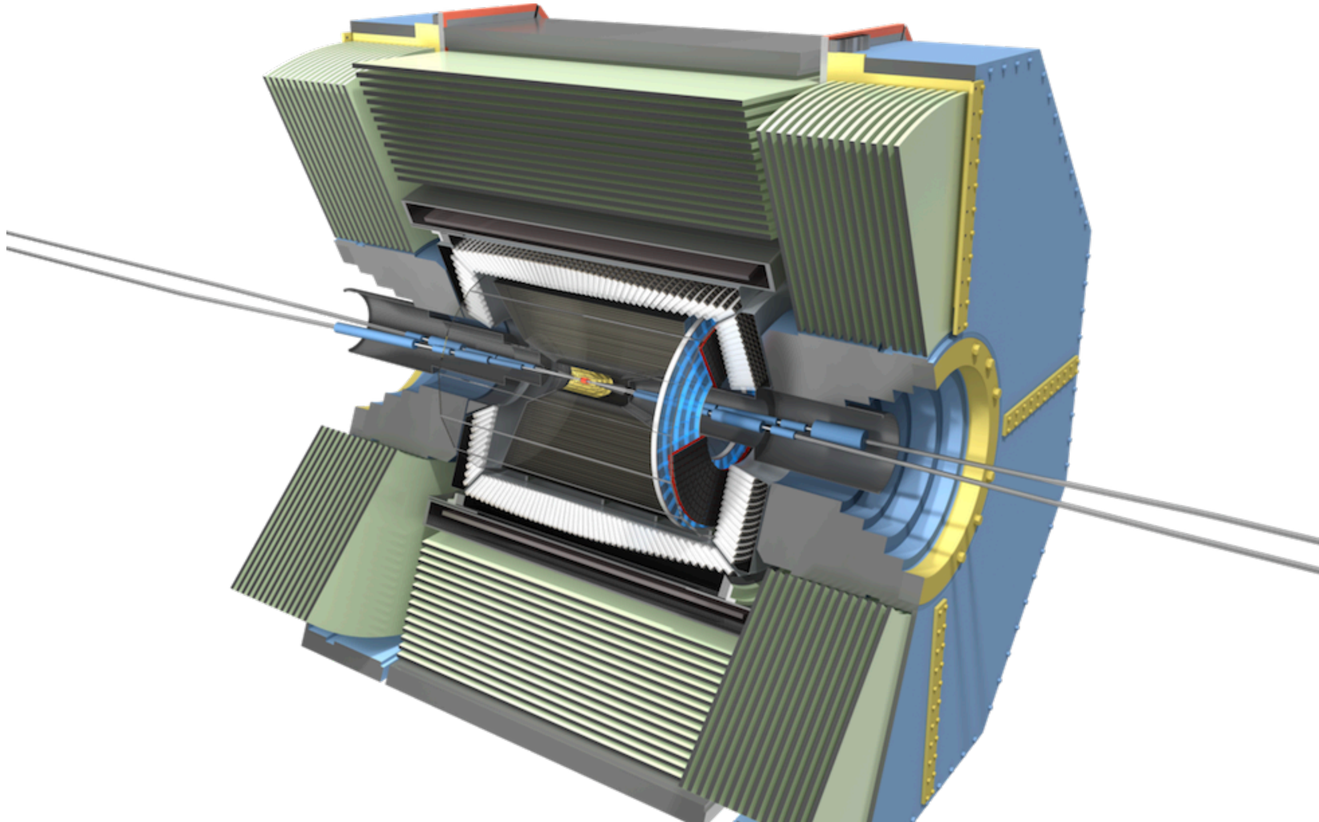
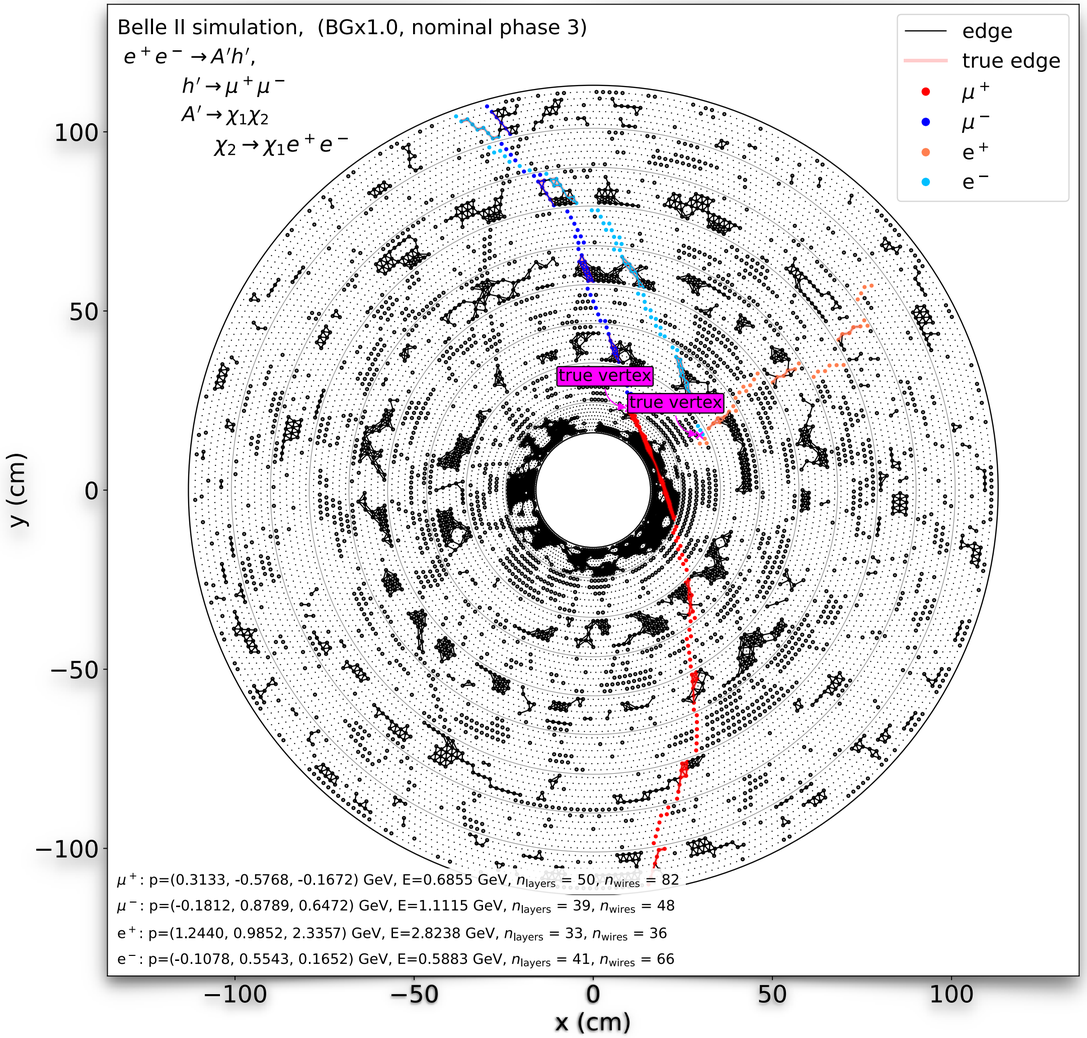


Overview for ML usage

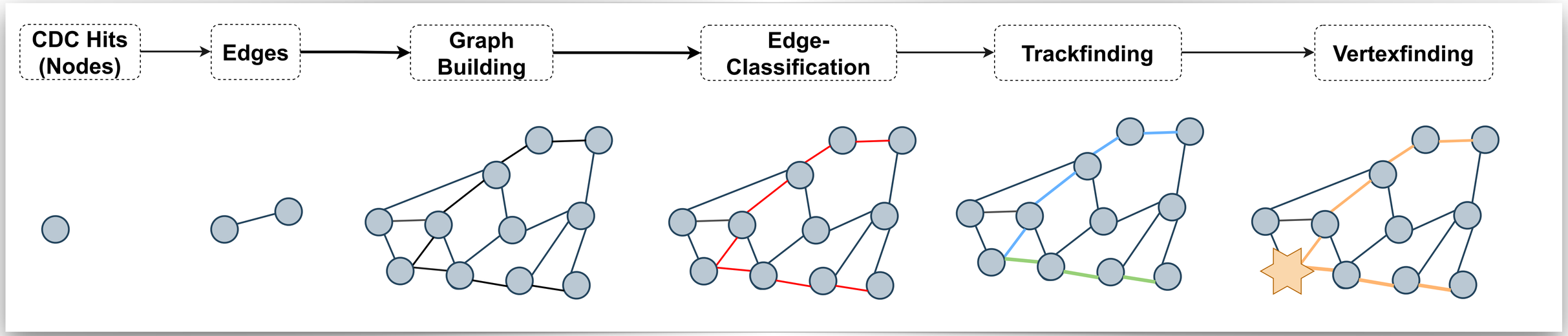
- Actively used:
  - used in most analysis for event classification. Most advanced tools “Full Event Reconstruction” and CNN-based flavour tagger with significant contribution from ETP.
  - used in offline reconstruction (mostly BDTs) for background-rejection in sub-detectors and particle identification
  - “NeuroZ” neural network trigger on multi-FPGAs lead by KIT-ITIV
- Active development:
  - Generative background generation (waveforms, pixel-patterns, …)
  - More complex real-time algorithms (vertexing, track-finding, cluster-splitting)
  - Anomaly detection for model-independent searches (much better SM understanding than ad pp colliders)

(Real-time) tracking using Graph Neural Networks (GNNs)

- **Physics challenges:**
  - Very high beam backgrounds
  - low pt tracks
  - (non-pointing) displaced vertices
- **Technical challenges:**
  - Need (very) low latency of O(µs) → FPGAs
    - Limited ressources on FPGA
    - Slow development cycles for everything non-standard
  - Stereolayers

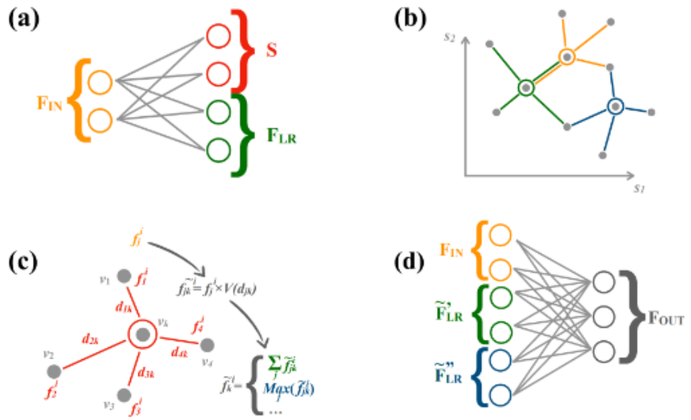


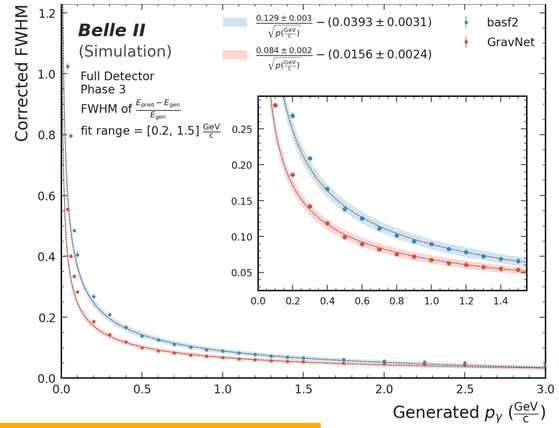
(Real-time) tracking using Graph Neural Networks (GNNs)



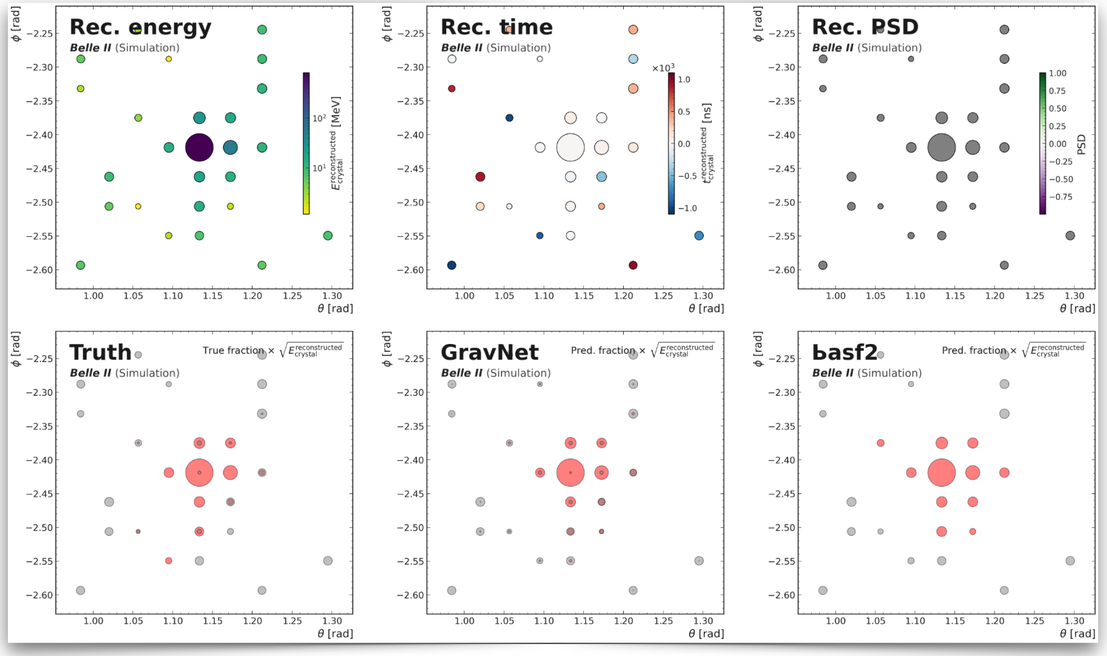
n-dimensional clustering

- **Physics challenges:**
  - High dimensional input data on irregular grids:
    - “5D”: x, y, z, time, energy (e.g. CALICE)
    - θ, ϕ, time, energy, pulse-shape, crystal dimensions
  - Very high backgrounds (noise)



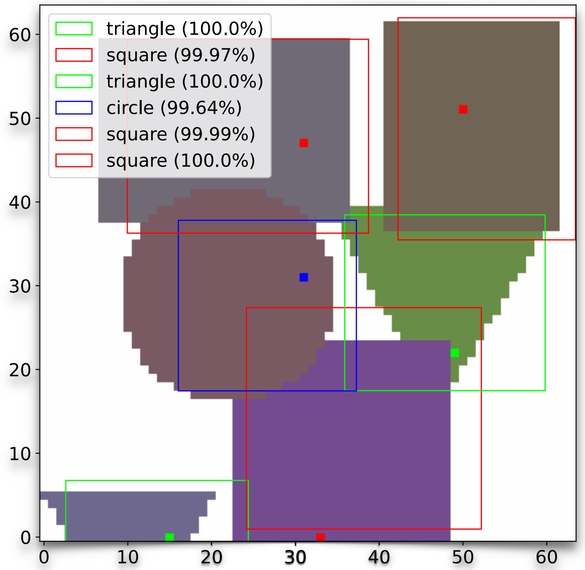


Belle II ECAL (full luminosity)

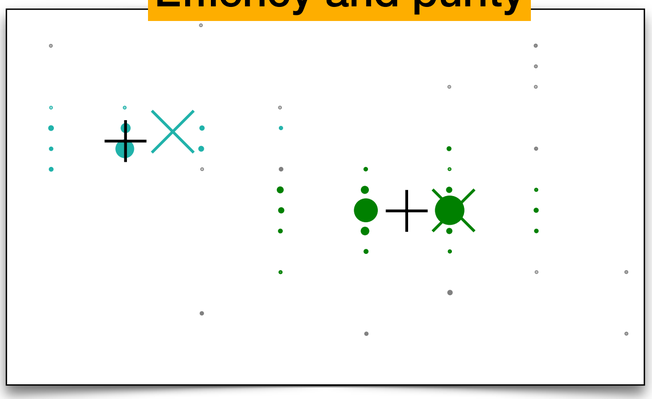


One-stage multi-object reconstruction: Object condensatio

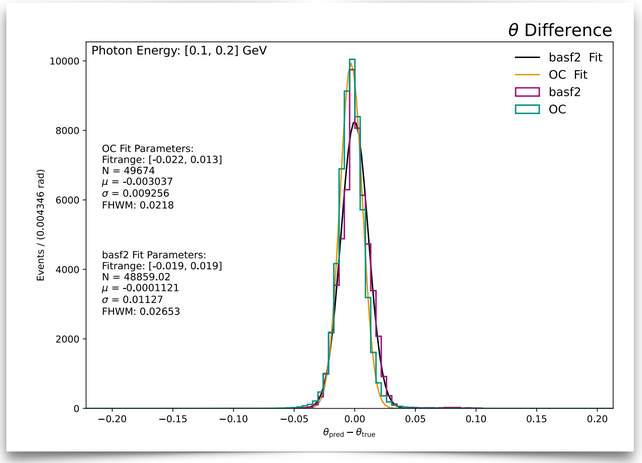
- **Physics challenges:**
  - Clustering (ECAL) and trackfinding for unknown(!) number of objects
  - Overlapping clusters and crossing tracks
- **Technical challenges:**
  - Optimization trade-off (multiple regression and classification targets)



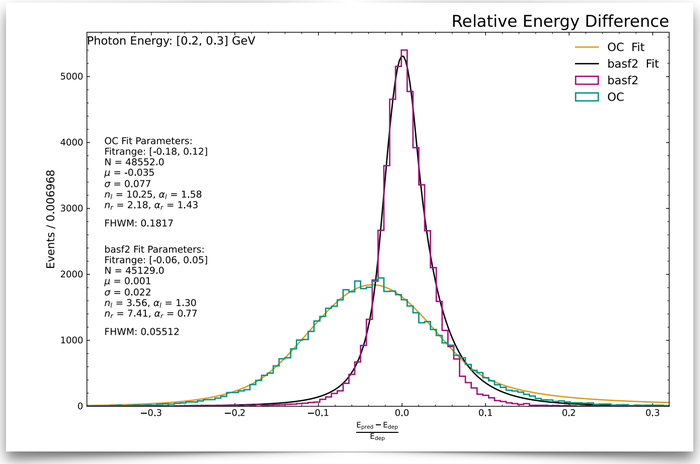
Effiency and purity



position resolution and splitting



energy resolution and threshold



Model-independent searches with anomaly detection

- **Physics challenges:**
  - Extended dark sector models with multiple mass scales, couplings, and lifetimes over potentially large SM backgrounds (No “out-of-distribution” events)
- **Current strategy: Autoencoders**
- **Challenge for future application:**
  - Real-time trigger application (inputs with much less precision compared to offline)
  - validation with data