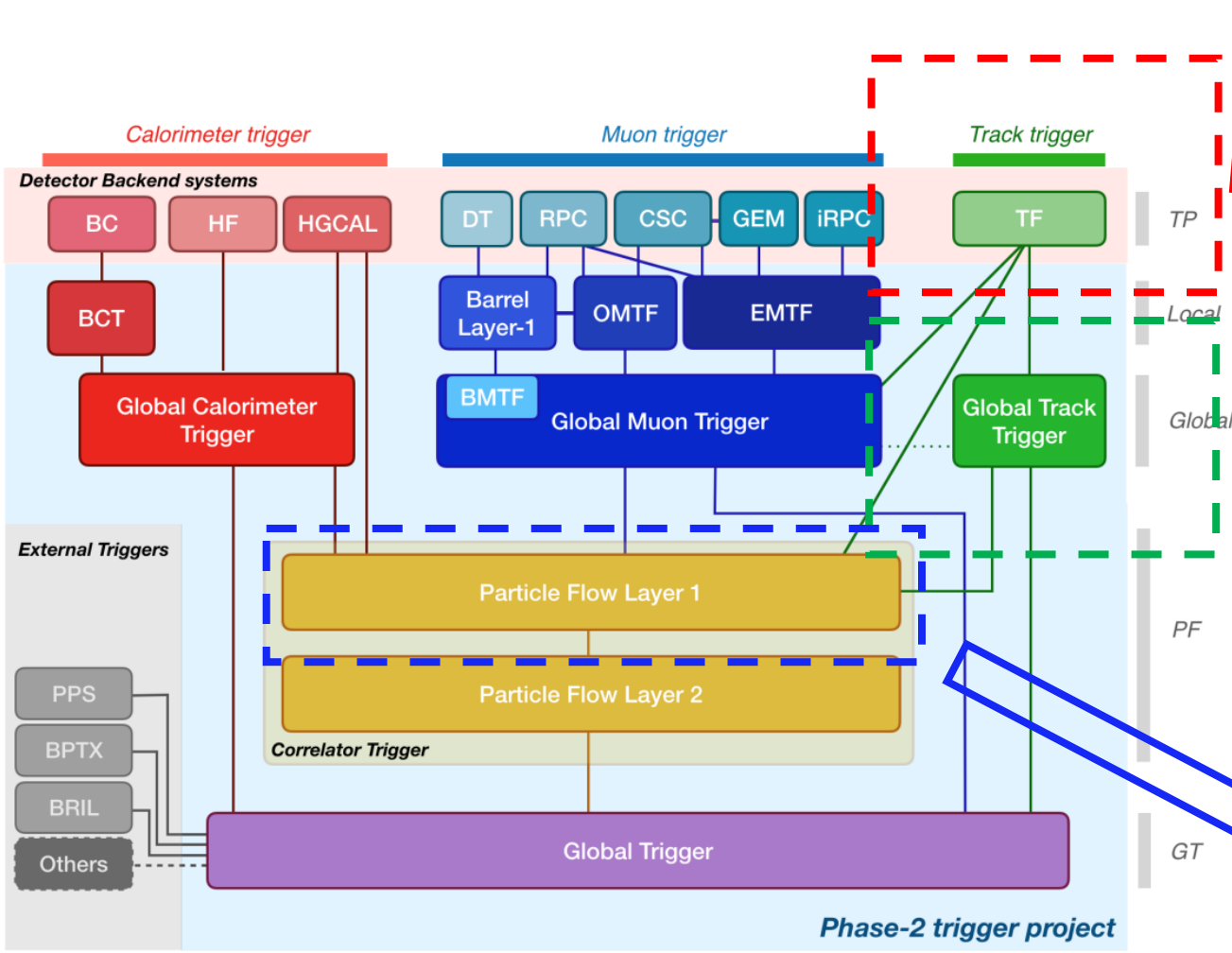
Imperial College London

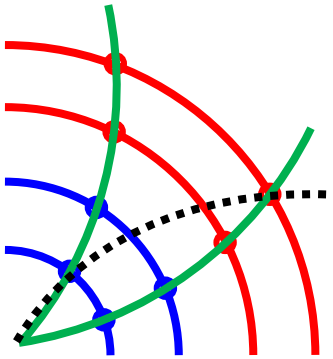
Harnessing charged particle tracks in the Phase-2 CMS Level-1 Trigger with ultrafast Machine Learning

Fast ML for Science 2023

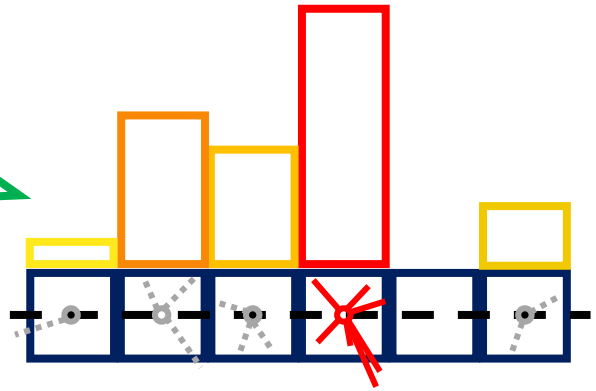
Christopher Brown



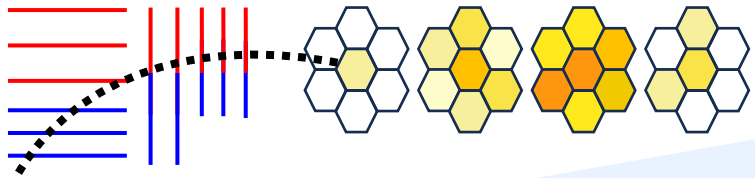
Fake Track ID



Vertex Reconstruction & Association



Electron ID



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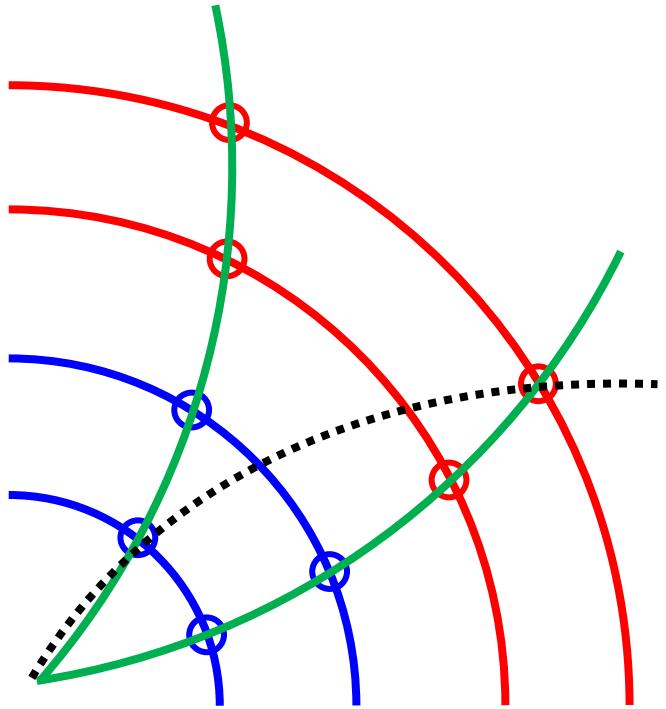
Fake Track ID

- Why?
  - High p_T fakes look like signal
- How?
  - BDT 60 trees, 3 deep
  - Trained on Φ,z_0,η,X^2,nstubs
- Performance?
  - Better than track fit cuts
  - 90% track finding efficiency vs 83% at same 12% fake rate
- Implementation?
  - Conifer
  - 13 clock cycles, < 0.3% resources of a VU13P



Track Finding and Neural Network-Based Primary Vertex Reconstruction with FPGAs for the Upgrade of the CMS Level-1 Trigger System

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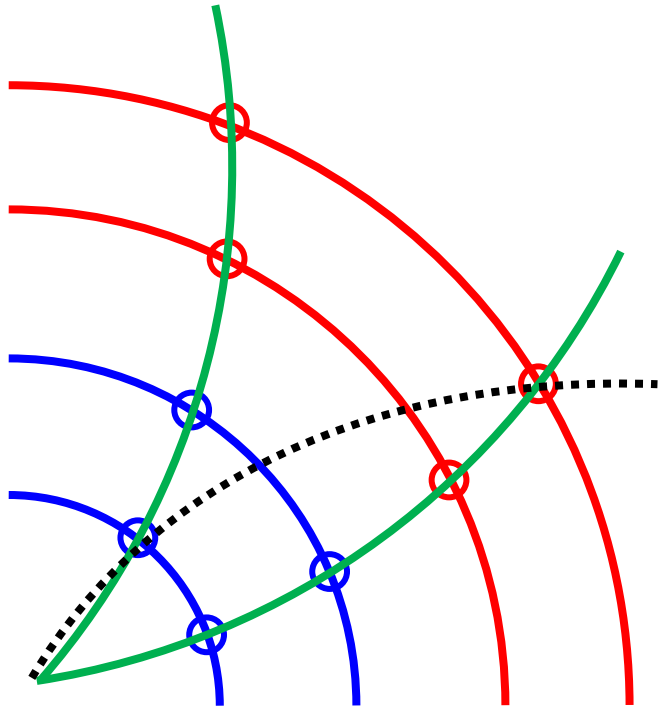

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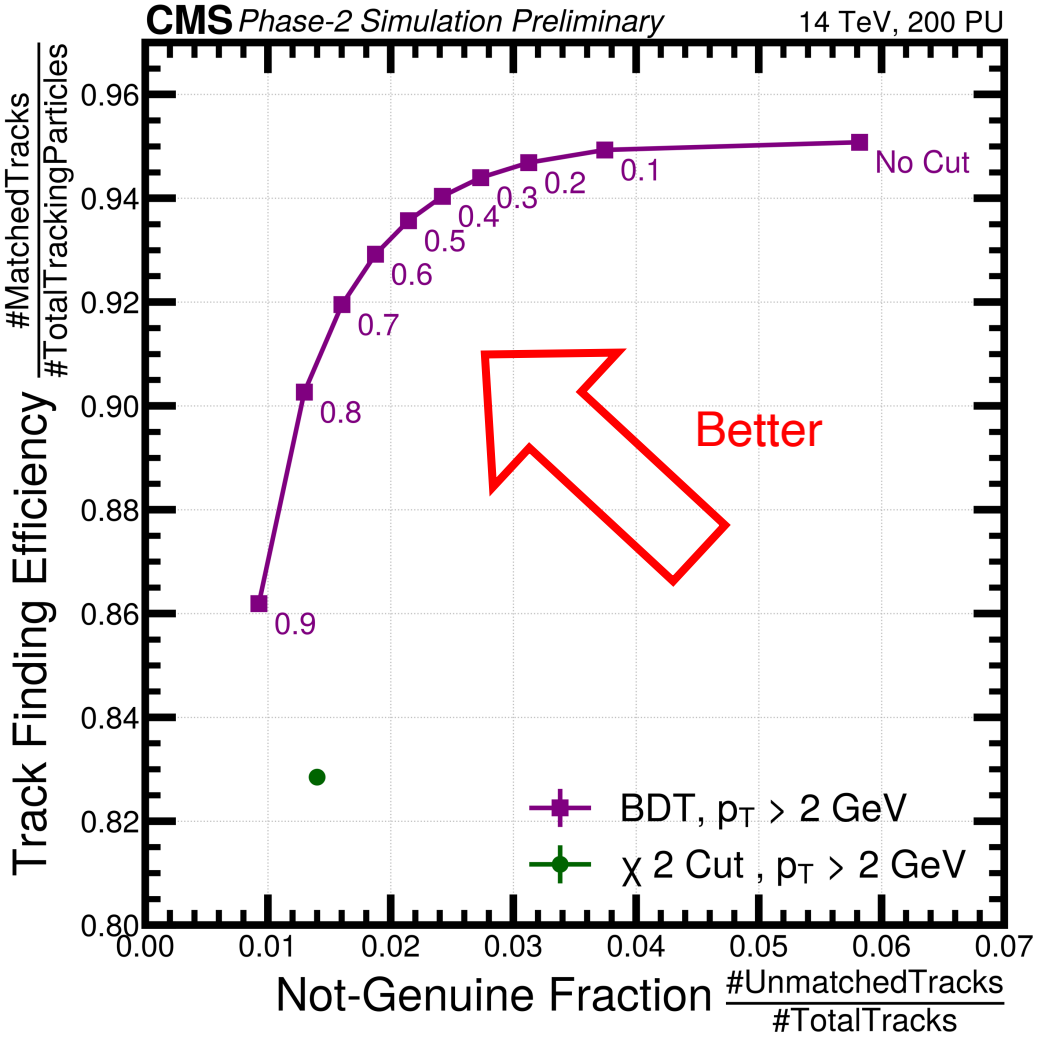

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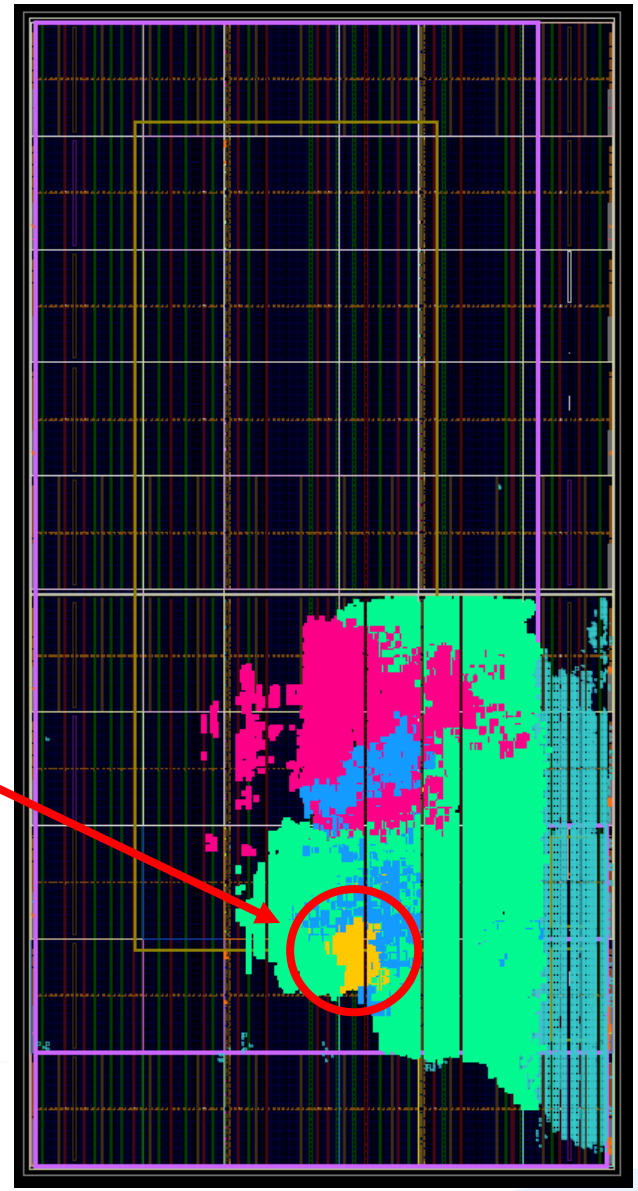
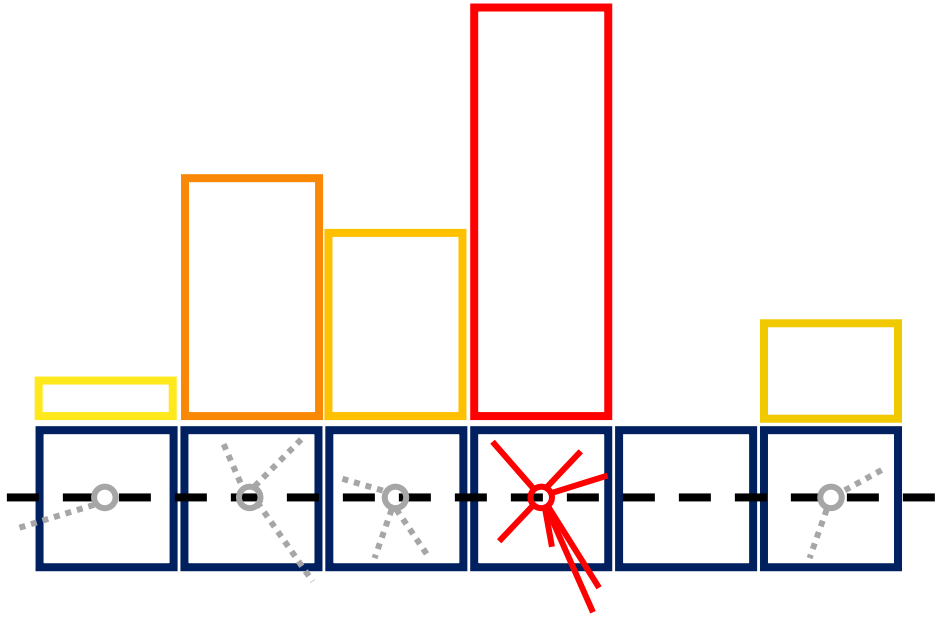


Track Finding and Neural Network-Based Primary Vertex Reconstruction with FPGAs for the Upgrade of the CMS Level-1 Trigger System

Vertex Location

- Why?
  - Vertex ID reduces downstream pileup
- How?
  - End-to-end neural network
  - Trained to find vertex and associate
  - Trained on p_T, fake ID BDT, η
- Performance?
  - Reduces vertex residual tails by 55%
  - Track to vertex association TPR 97% vs baseline's 91% at the same FPR
- Implementation?
  - hls4ml
  - < 100 ns vertex finding latency
  - < 30% of VU13P



Neural Network-Based Primary Vertex Reconstruction with FPGAs for the Upgrade of the CMS Level-1 Trigger System

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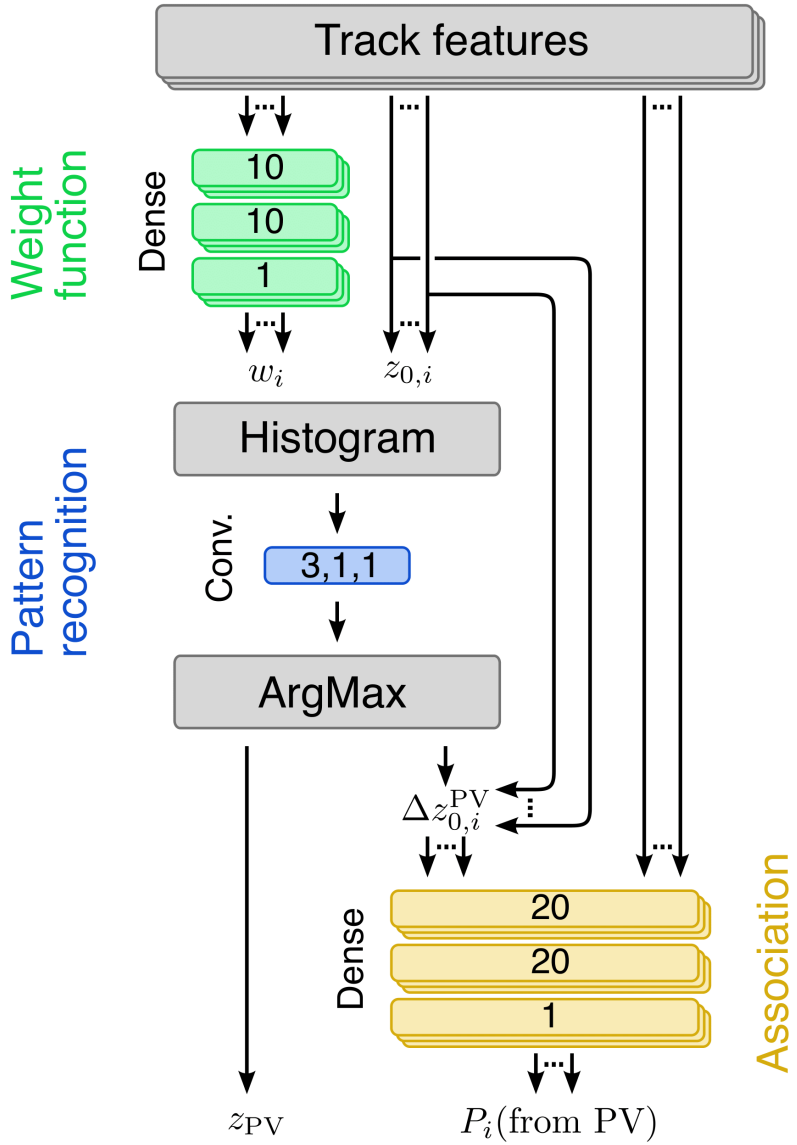

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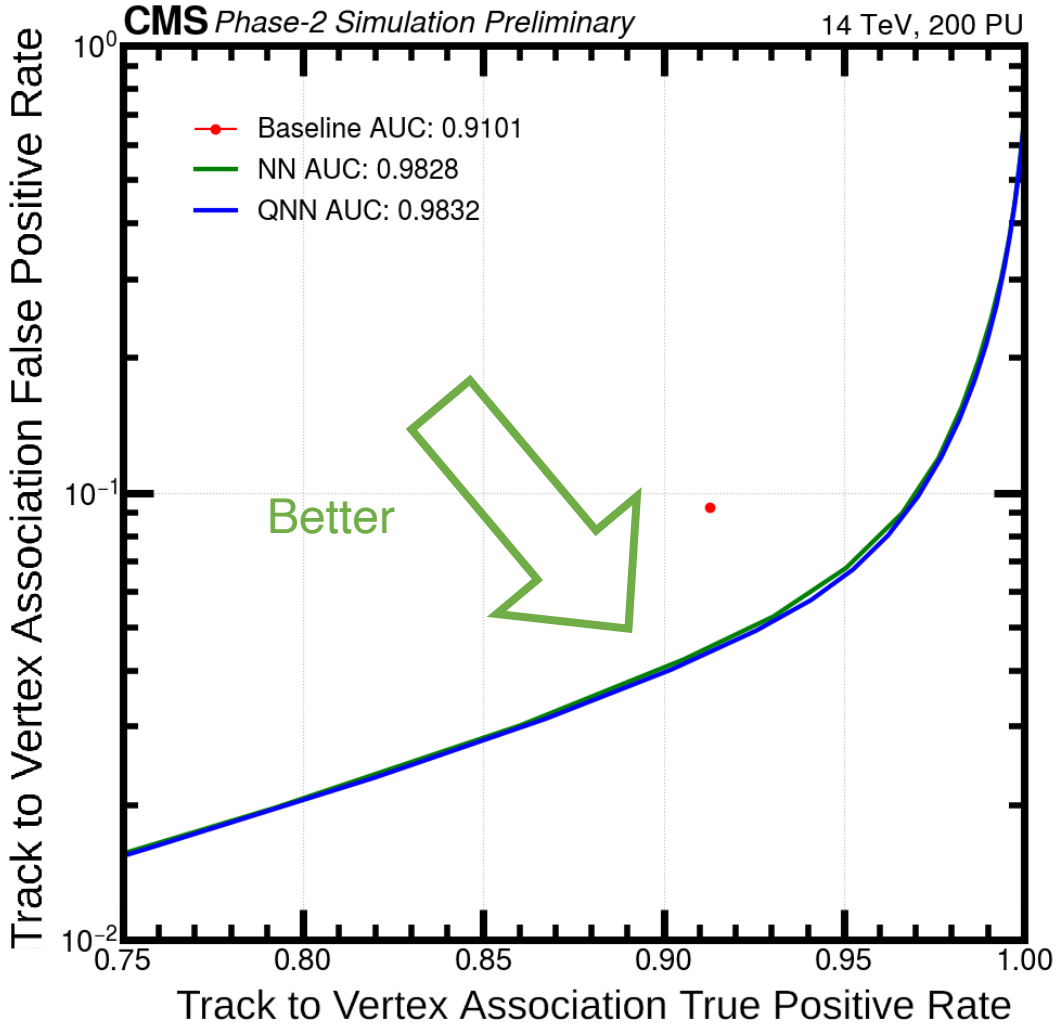

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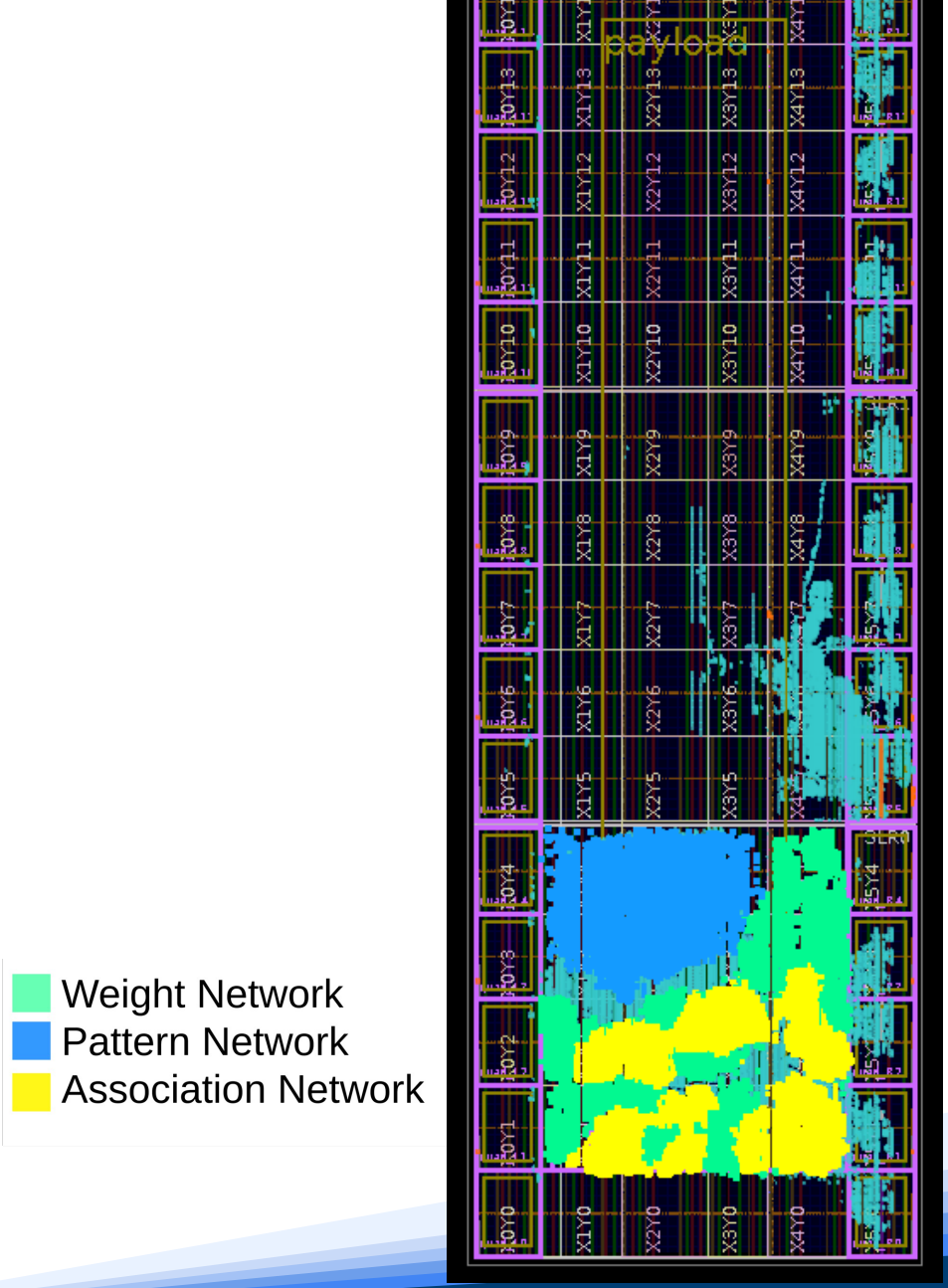

Neural Network-Based Primary Vertex Reconstruction with FPGAs for the Upgrade of the CMS Level-1 Trigger System

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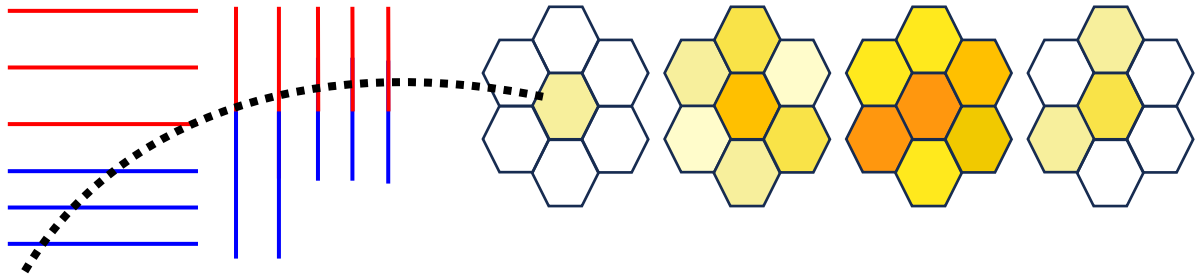
Electron ID

- Why?
  - Bremsstrahlung makes electron ID hard
- How?
  - BDT
  - Trained HGCAL cluster properties, track properties and track-to-cluster matching
- Performance?
  - Faster turn-on
  - 5% efficiency increase across η
- Implementation?
  - Conifer
  - < 100 ns evaluation
  - 3.1% LUTs and 1.6% of VU13P



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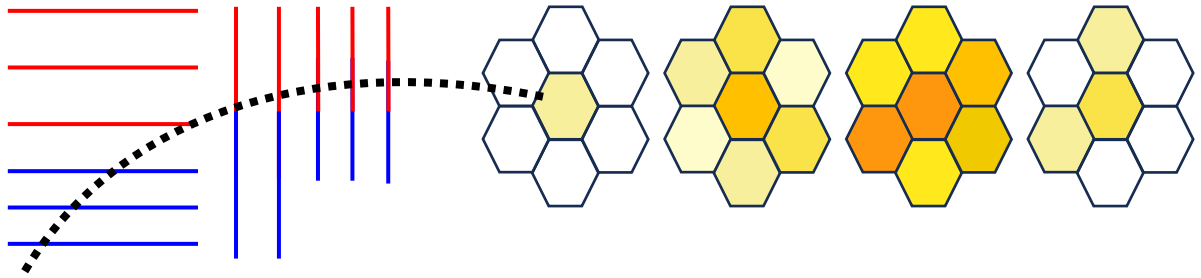

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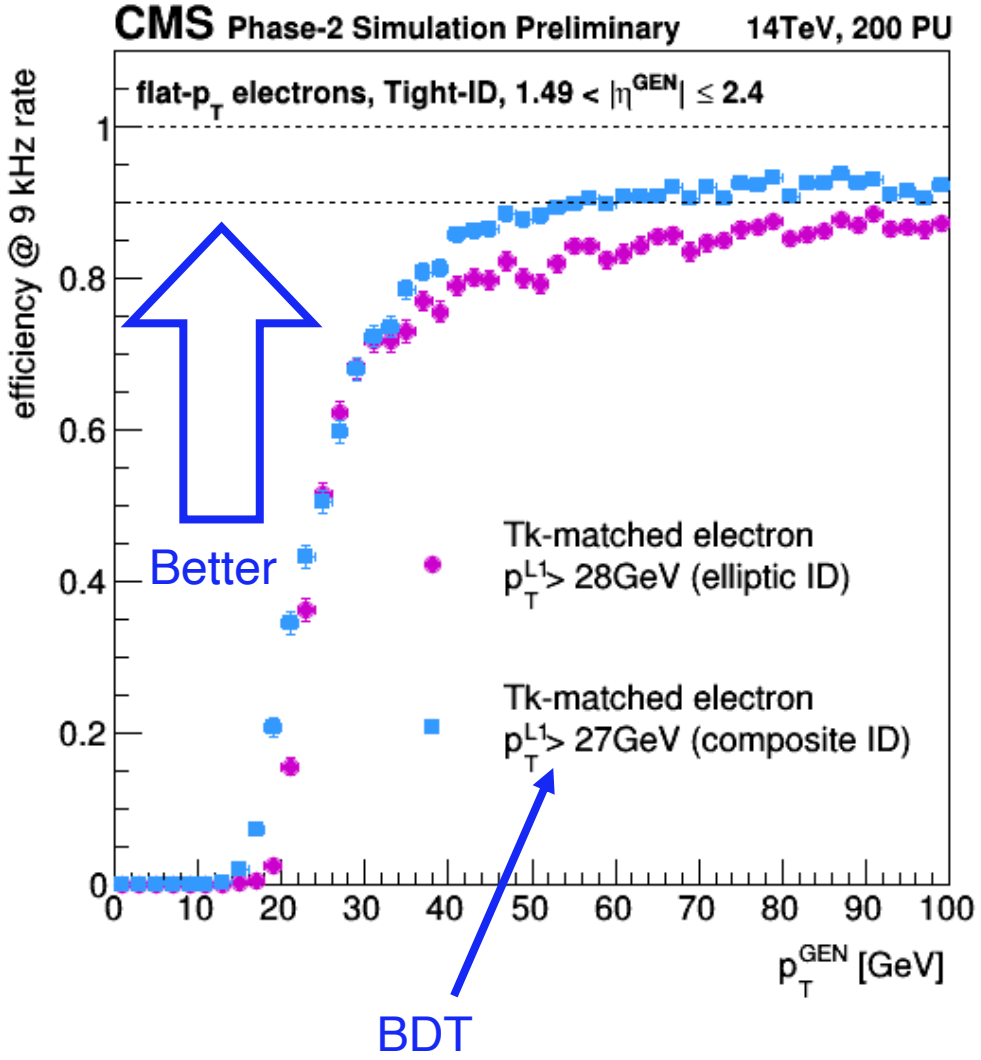

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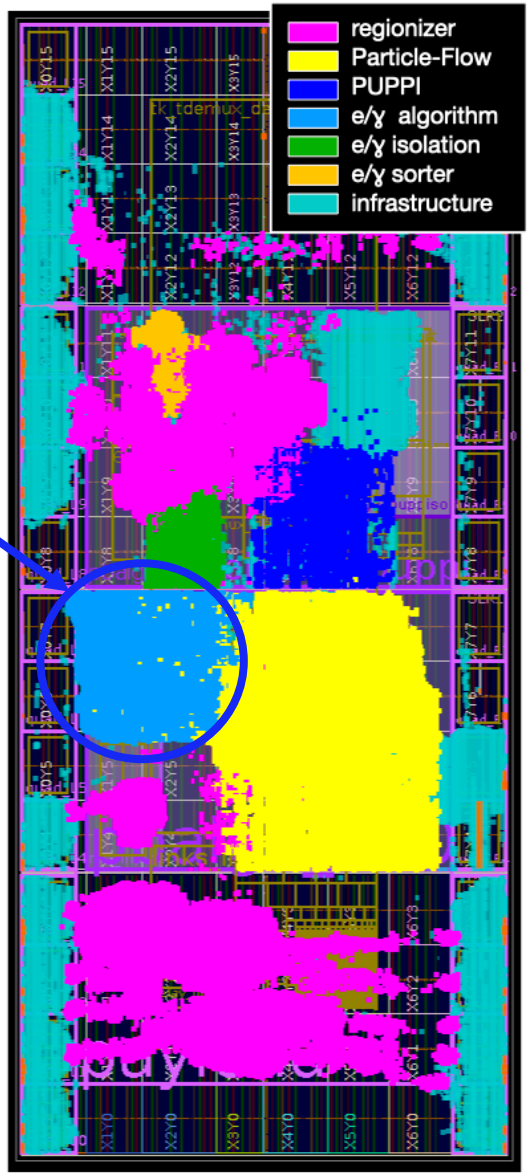
Small footprint



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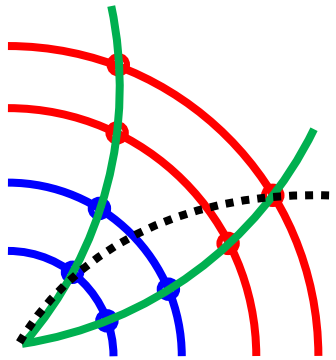
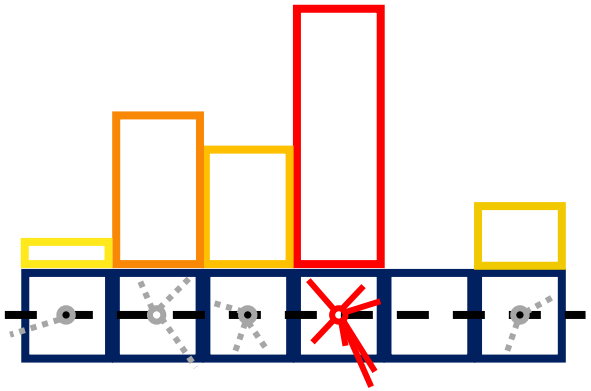
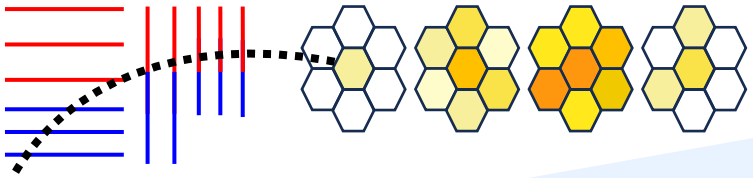
Conclusions

- Track finding essential for L1 trigger
- BDTs for fake track ID
- NNs for vertex finding and association
- BDTs for electron ID
- ML enhances L1 trigger

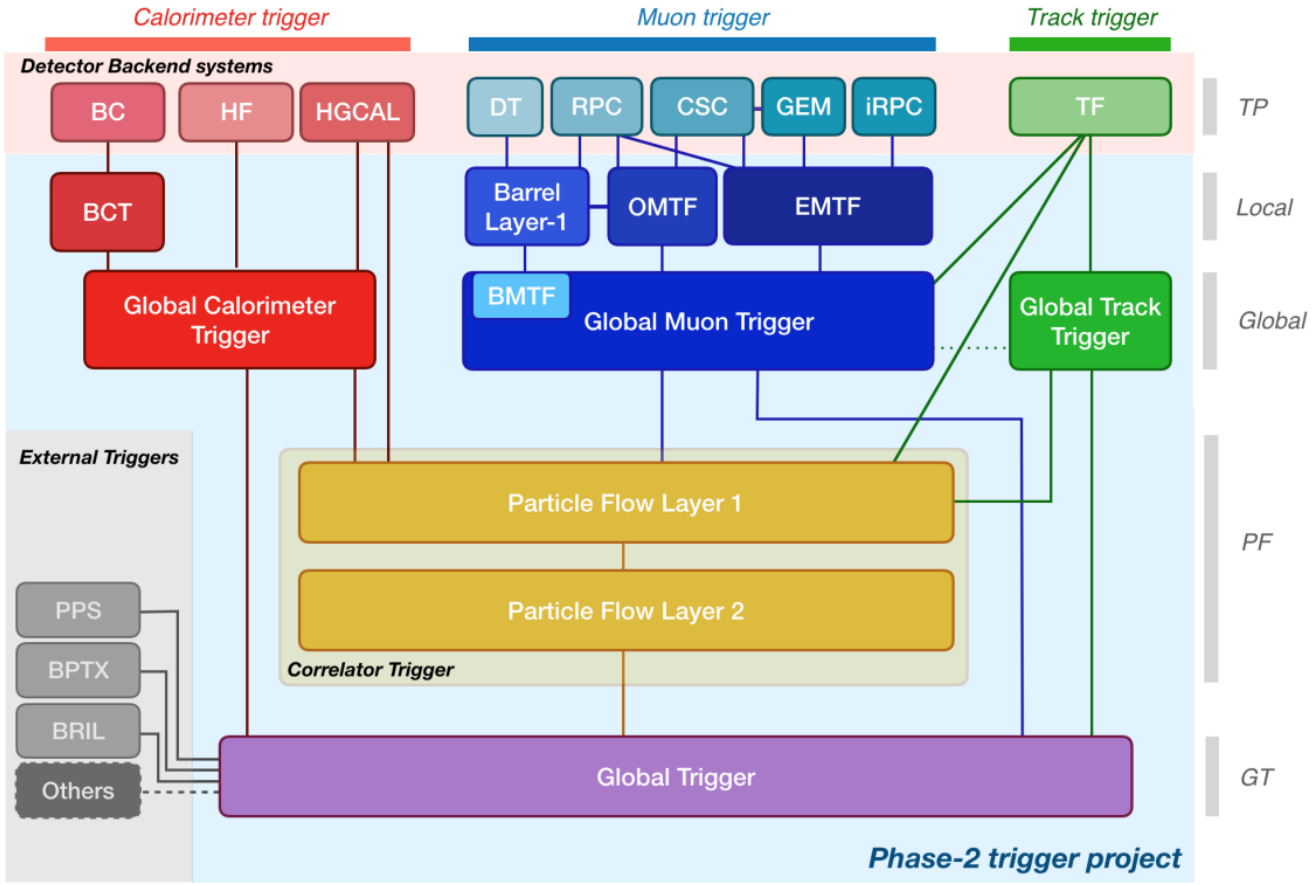






CMS Phase-2 Level-1 Trigger

- 40 MHz → 750 kHz
- 4 μs → 12.5 μs
- 200 PU to find a signal in
- Charged particle tracking
  - p_T > 2 GeV
- FPGA architecture
  - ML throughout



The Phase-2 Upgrade of the CMS Level-1 Trigger

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