

Traineeships in Advanced Computing for High Energy Physics (TAC-HEP)

FPGA module training

Week-13

Lecture-24: 01/05/2025



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Content



So far

HLS Pragmas:

- Aggregate
- Expression_balance
- Latency
- Performance
- Protocol
- Stable
- Inline
- Interface
- Stream
- Dataflow
- Pipeline
- Unroll
- Dependence
- Loop_flatten
- Loop_merge
- Loop_tripcount
- Array Partition
- Array reshape
- Allocation
- Occurrence
- Bind_op
- Bind_storage
- Function_instantiate

Today

- Project discussion



- You may choose to undertake the project individually or collaborate in a group of up to three or four members
- You are free to select one of the proposed projects
- **Alternatively**, you are welcome to propose your own idea

Project-1



Calorimeter Level-1 trigger system in real HEP experiment

Process calorimeter data to cluster energy deposits, perform the sorting of these clusters, make triggerable objects – photon, jet candidates, MET

Ingredients



1. *Input Data*

- Simulate a grid of calorimeter cells (e.g., 2D array of energy deposits: $\text{Eta} \times \text{Phi}$) **or a QCD sample**
- **Optional:** Use already simulated sample (containing CMS HCAL/ECAL or ATLAS calorimeter information)

2. *Clustering Algorithm*

- Perform **sliding window** clustering:
 - Identify **local maxima** in the calorimeter grid.
 - Build **clusters (3x3, 5x5, 7x7)** by summing nearby cells – why would you need different sizes?
 - Thresholds for seed and sum
 - Keep the seed positions

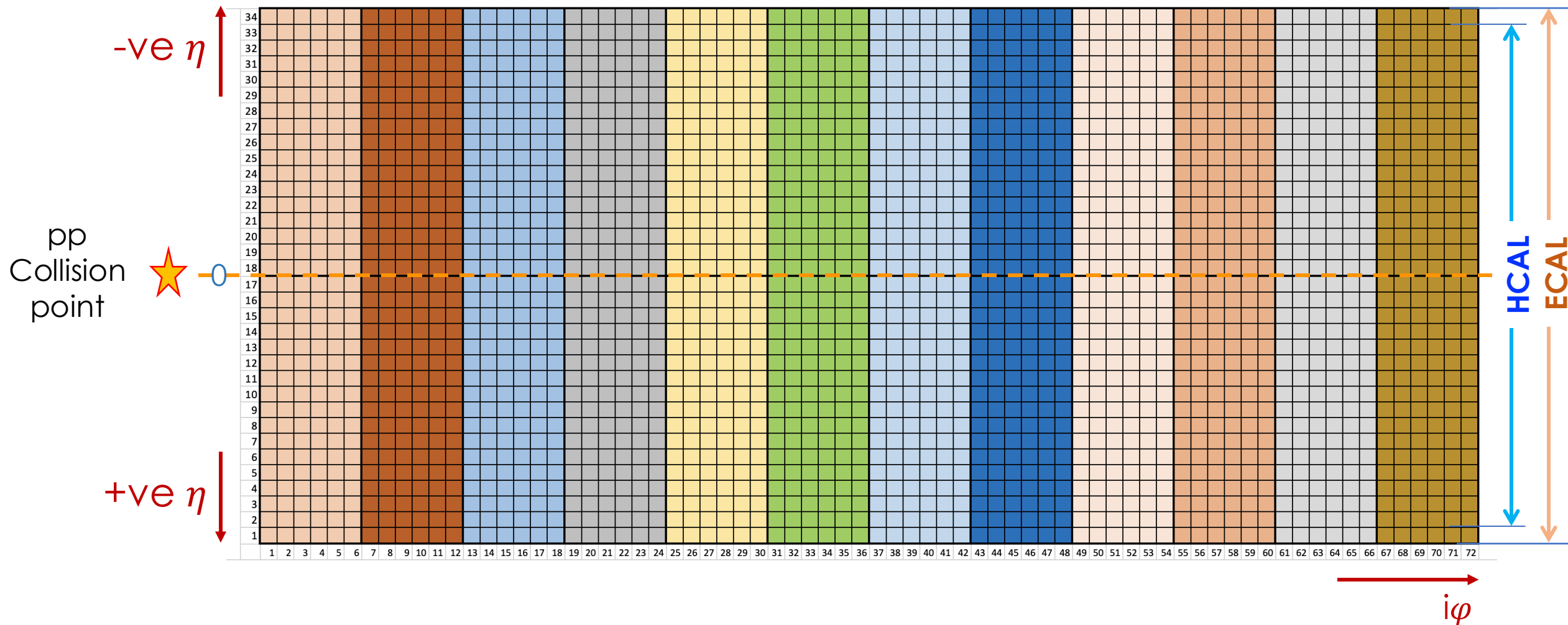
3. *Sorting (try different algorithm)*

- Sort clusters by **transverse energy (ET)** or position
- Output top-N clusters (for example: for jet candidates, photon/electron candidates, MET)

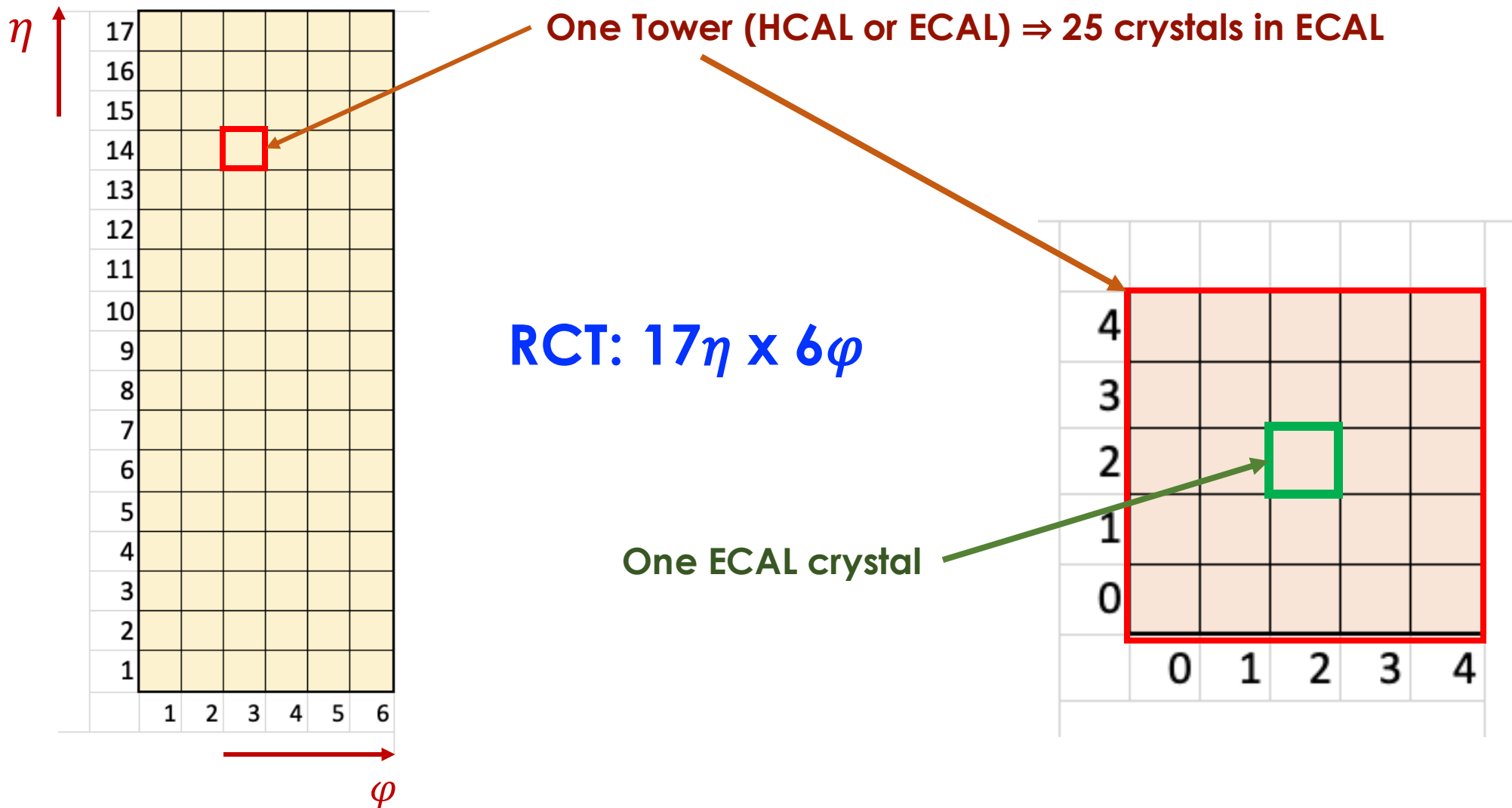
4. *Trigger Object Creation and send them out*

- Use cluster properties to generate **trigger candidates**:
 - Total transverse energy (HT)
 - Missing transverse energy (MET) using vector sum
 - Jet or EM candidates

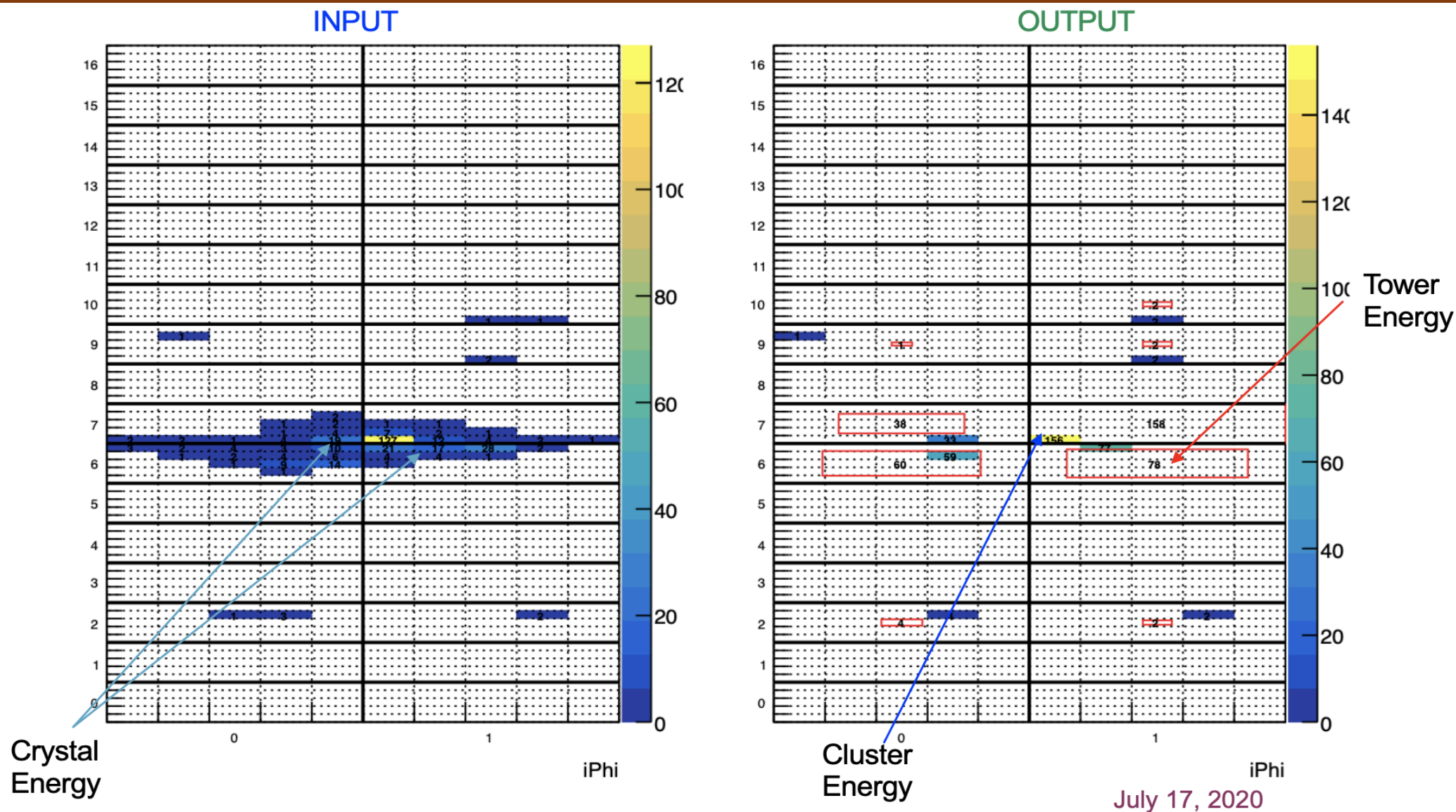
Example: Barrel Calorimeter Segmentation



Small Portion



Example: Clustering



Project - 2



Real-time particle track reconstruction from simulated detector hits

- **Cluster** detector hits
- **Sort** them spatially or temporally
- Use a **Kalman filter** to estimate particle trajectories
- Output a list of candidate tracks in real-time

Ingredients



1. *Input Simulation*

- Take simulated tracker hits

2. *Clustering Algorithm*

- Group nearby hits in the same detector layer to form **cluster candidates** (e.g., based on distance or time)
- Clustering can use a simple approach or sliding window logic

3. *Sorting Hits*

- Sort hits by layer number, timestamp, or X/Y position to prepare for track fitting

4. *Track Fitting using Kalman Filter*

- Apply a Kalman filter to clustered and sorted hits to estimate track parameters (position, momentum, angle)

5. *Send tracks to output*

Project-3



Process data from a *Liquid Argon Time Projection Chamber (LArTPC)* used in neutrino experiments

- Identify and classify **neutrino interaction events** in real-time

Ingredients



1. *Input Simulation*

- Simulated ionization signals from neutrino interactions

2. *Clustering*

- Apply a **sliding window** or any other clustering to group adjacent hits (both spatial and temporal).

3. *Sorting*

- Sort hits or clusters by time (drift) or position to prepare for reconstruction
- Sort and filter (maybe Kalman filter) clusters by time/space/energy.

4. *Classification*

- Simple rules: straight tracks = muons; diffuse = electrons; high energy = neutral pion decay?

5. *Send out sorted, classified events*

Objective



- *Implement algorithms*
- *Optimize the latency and resource utilization using all possible pragma*
- *Synthesize the code*
- *Feel free to be more adventurous and add more features to algorithms*

Reminder: Assignments



- Assignment-1 (13-02-2025)
- Assignment-2 (18-02-2025)
- Assignment-3 (27-02-2025)
- Assignment-4 (18-03-2025)
- Assignment-5 (18-03-2025)
- Assignment-6 (27-03-2025)
- Assignment-6a (15-04-2025)
- Assignment-7 (15-04-2025)
- Assignment-8 (24-04-2025)

Try to submit all assignments by May 10th

In case of concerns reach out via email/slack

Uploaded to cernbox: <https://cernbox.cern.ch/s/gmUqRDHTxDLqx4M>

Indico: <https://agenda.hep.wisc.edu/event/2332/timetable/?view=standard#day-2025-05-01>

Send via email: varun.sharma@cern.ch



Questions?

Acknowledgements:

- <https://docs.amd.com/r/2024.1-English/ug1399-vitis-hls>
- [ug871-vivado-high-level-synthesis-tutorial.pdf](#)