SLHC Calorimeter Trigger at phase I

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SLHC Upgrade Workshop

FNAL

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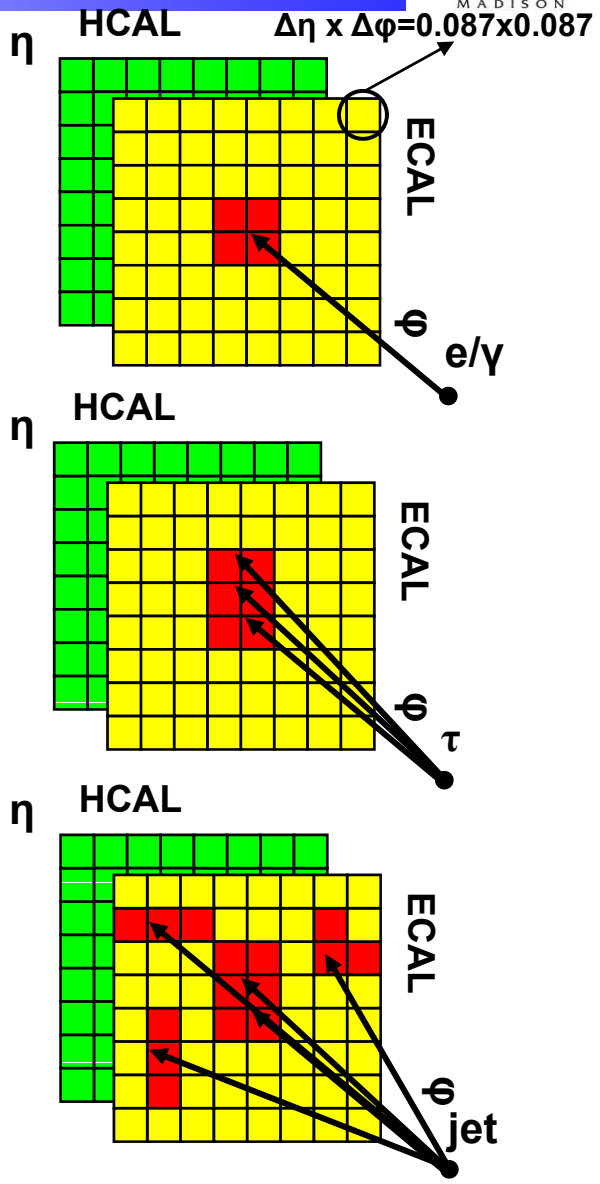
Introduction

- SLHC Calorimeter trigger goals
  - Provide High performance triggers in the SLHC environment
    - Electrons and photons: Provide similar performance with current trigger also in SLHC conditions
    - Taus: Improve background rejection so that the thresholds will be relatively low
    - Jets: Provide high energy and position resolution
  - Support communication with the tracking trigger
    - High spatial resolution so that tracks can be mapped to Calorimeter objects
    - Counting of tracks and track Isolation will resolve electrons from photons , Taus from jets

Calorimeter signatures

- **Electrons/Photons**
  - Spatially confined in a cluster of 2x2 trigger towers
  - Significantly higher ECAL contribution
  - Isolated e/γ should have low energy deposits in the surrounding area
- **Taus**
  - Confined in 2x3 Clusters
    - 3 prongs/1 prong + π^0s have wider φ profile
  - Small energy leak in surrounding towers
- **Jets**
  - Most of the energy confined in a central core
  - For jets over 20 Gev the energy is included in a 8x8 region

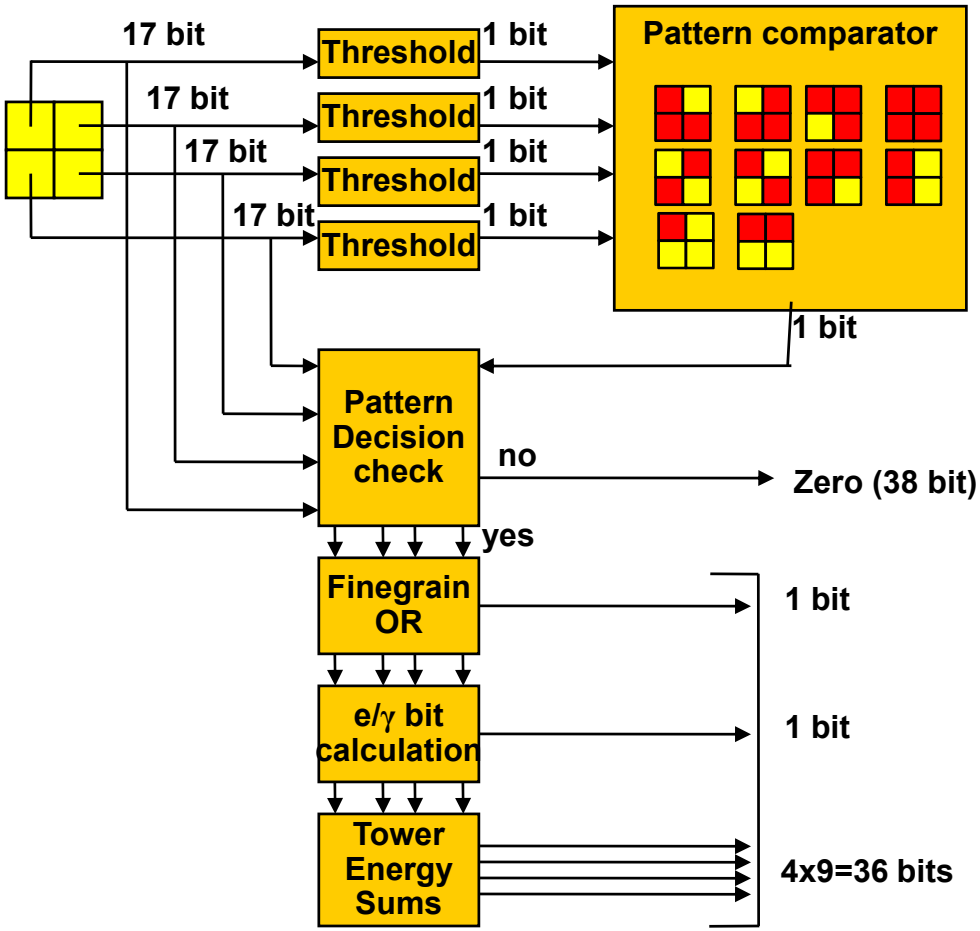


Algorithm Overview

- Particle Cluster Finder
  - Takes Calorimeter TPG input and applies tower thresholds
  - Creates overlapped 2x2 clusters
- Cluster Overlap Filter
  - Removes overlap between clusters
  - Identifies local maxima
  - Prunes low energy clusters
- Cluster Isolation and Particle ID
  - Applied to local maxima
  - Calculates isolation deposits around 2x2,2x3 clusters
  - Identifies particles
- Jet reconstruction
  - Applied on filtered clusters
  - Groups clusters to jets
- Particle Sorter
  - Sorts particles and outputs the most energetic ones
- MET,HT,MHT Calculation
  - Calculates Et Sums, Missing Et from clusters

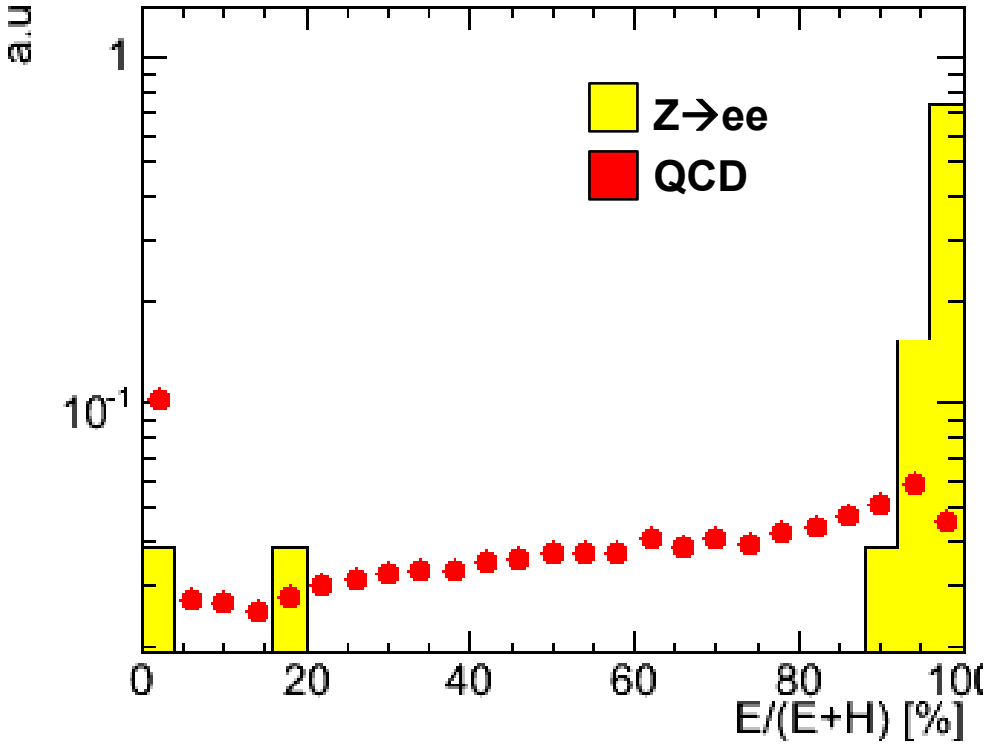
Particle Cluster Finder (I)

- Input
  - Each clustering block takes as input four Towers (4x17 bits)
  - Tower
    - 4 ECAL Et bits 4 HCAL Et bits , 1 finegrain bit
- Algorithm
  - Apply ECAL,HCAL Et activity thresholds on the towers
  - For each four towers create a 2x2 cluster
  - If cluster pattern is not satisfied cluster is dropped
  - Calculate e/γ compatibility bit
  - Output a cluster (38 bits)
    - 4 Towers (4x9 bits, E+H)
    - OR of the finegrain bit
    - e/γ Compatibility bit
  - Algorithm is applied with a step of one tower (overlapped clusters)



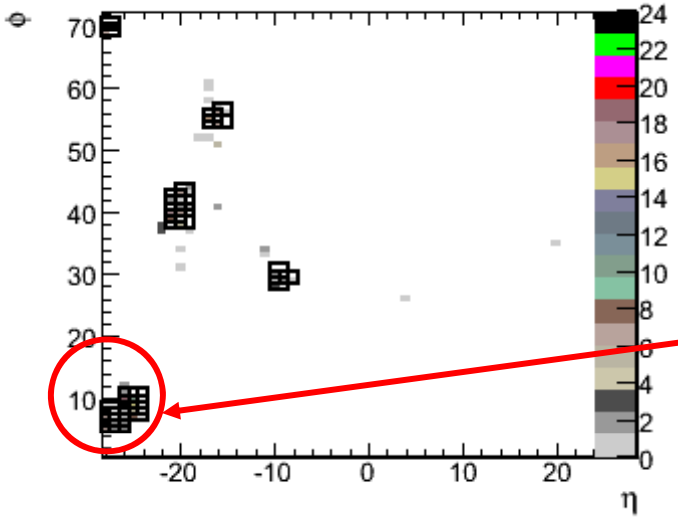
Electron/ Photon bit

- **ECAL energy fraction is a straightforward selection cut**
- **Looking towards a generic LUT implementation**



Clustering examples

TTbar -NoPU



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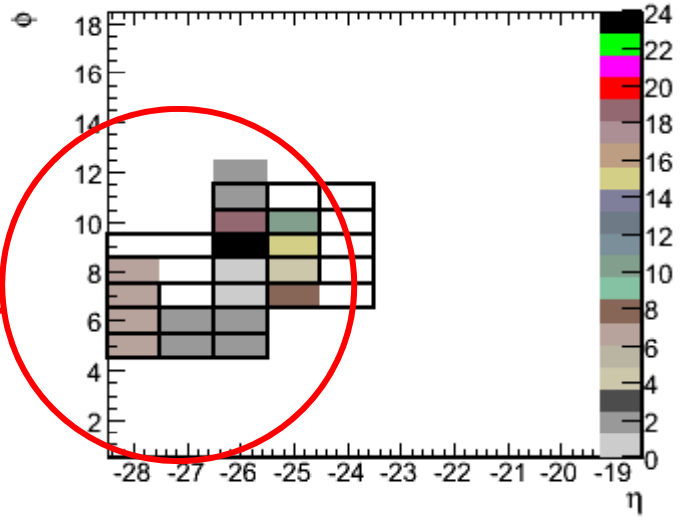

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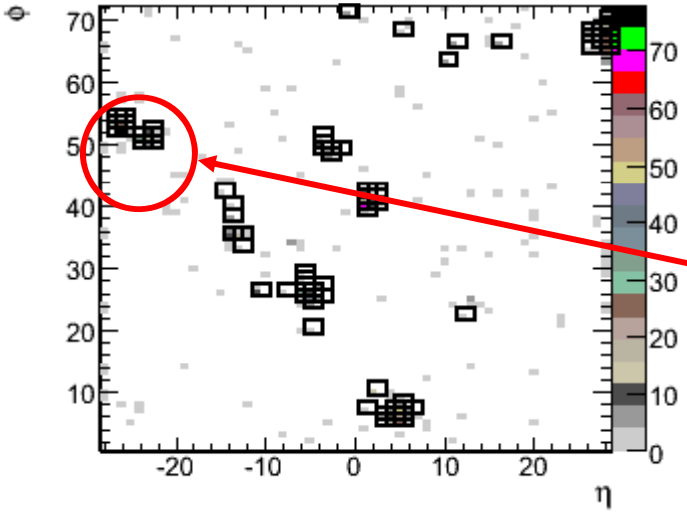

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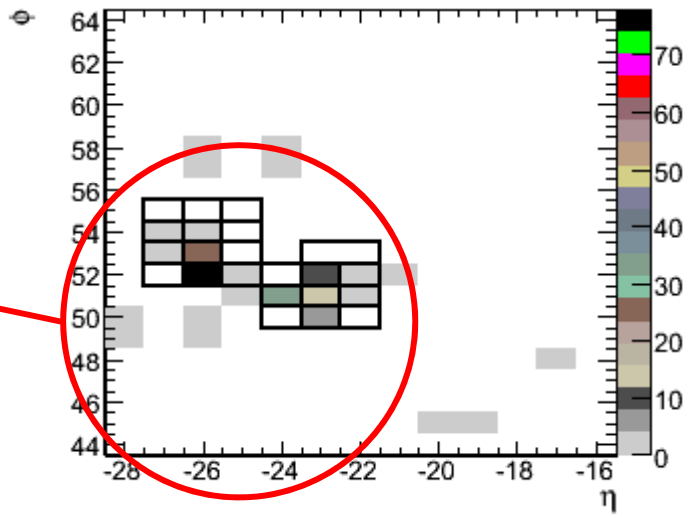
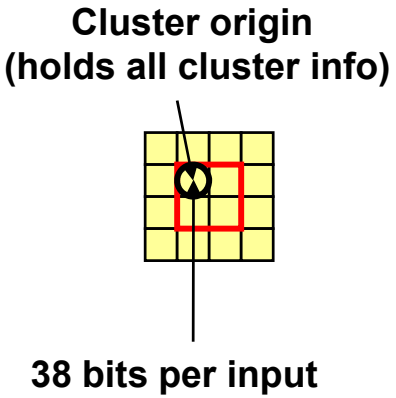
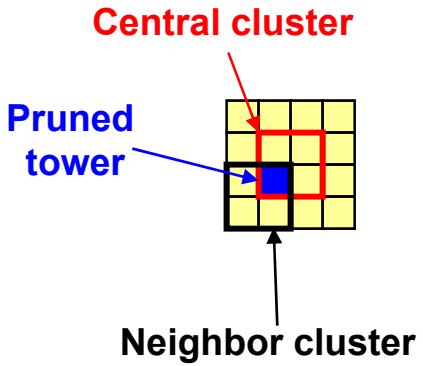
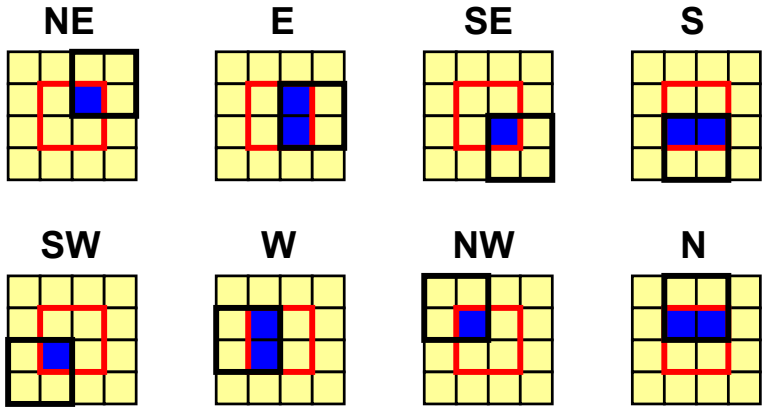


Cluster Overlap Filter

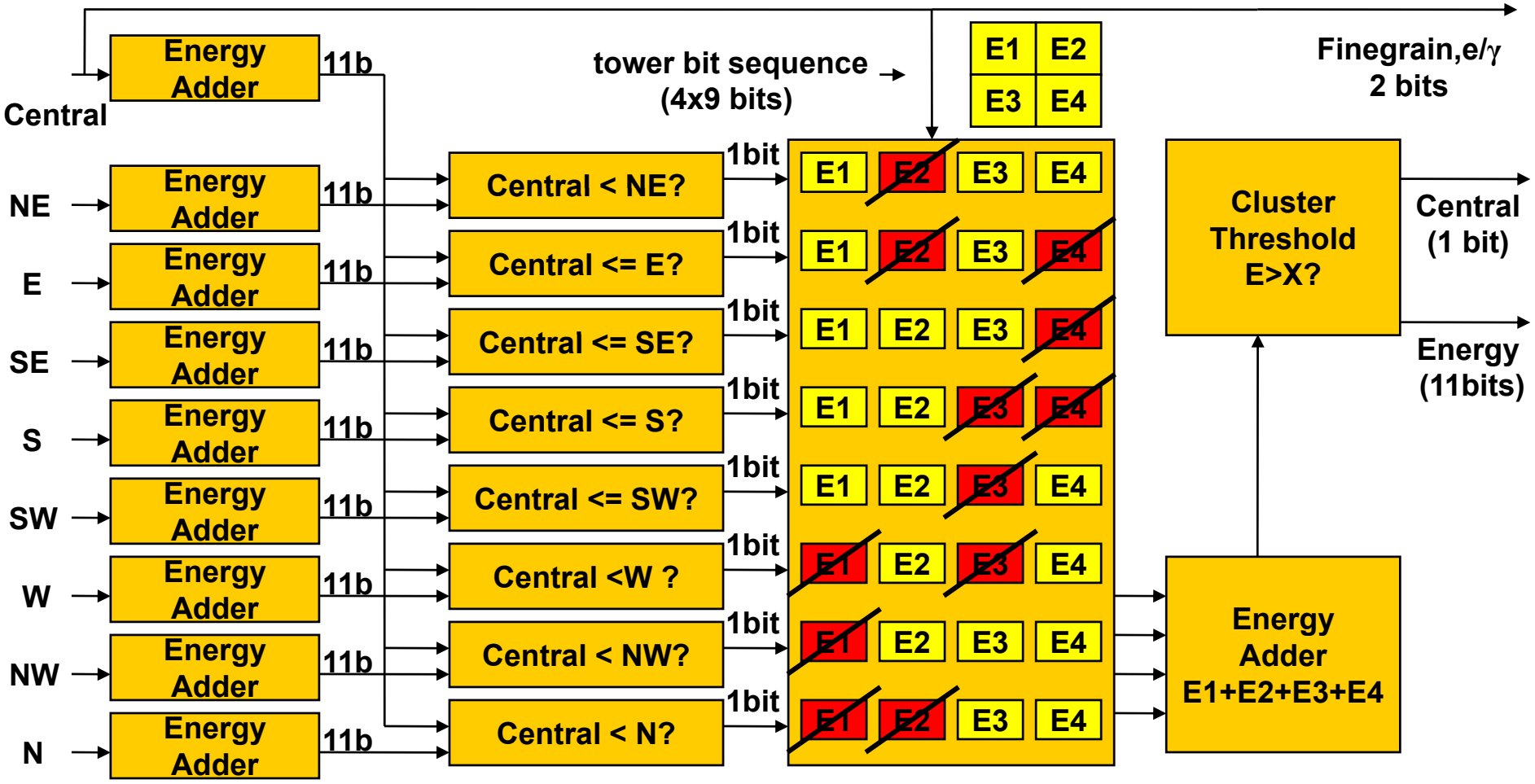
- Cluster Overlap Filter is applied on the clusters produced by the Particle Cluster finder
- The algorithm takes as input 9 clusters
  - A central cluster
  - The 8 neighboring clusters
- Algorithm
  - For a pair of the central cluster and any neighbor:
    - If central Et <neighbor Et:
      - Remove overlapping towers with the neighbor from the central cluster
    - If no towers are pruned
      - Cluster is characterized as central
  - After pruning threshold is applied in cluster energy
  - Output
    - 11 bits of cluster energy
    - 1 Finegrain Bit, 1 e/γ bit, 1 central bit





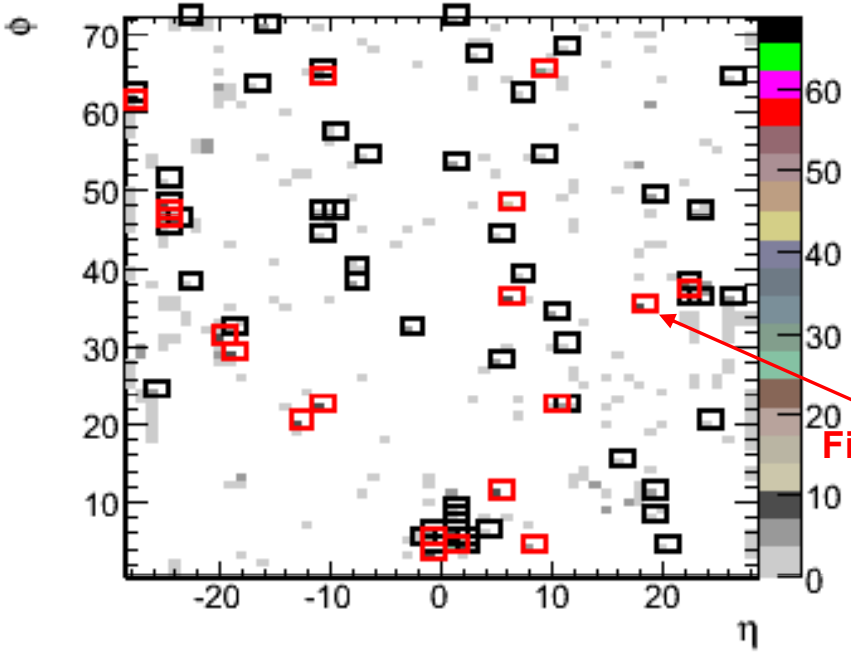


Cluster Filter Logic



Cluster Filtering examples

TTbar - PU



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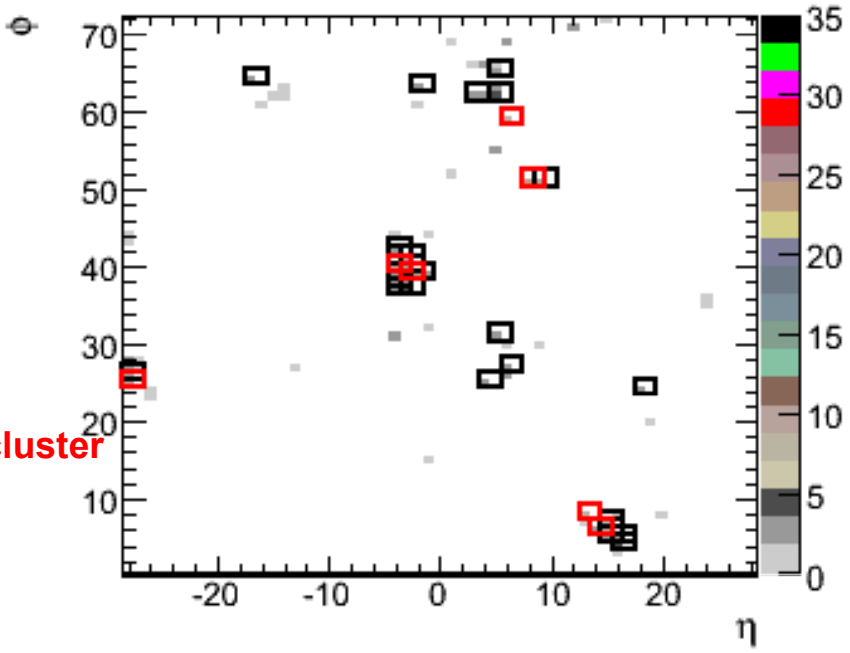
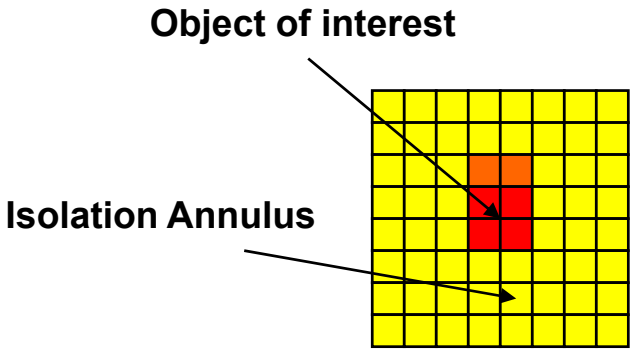


- A large portion of the clusters are removed in the filtering step
- The thresholds for this test are relatively low
  - Cluster Threshold = 3 GeV

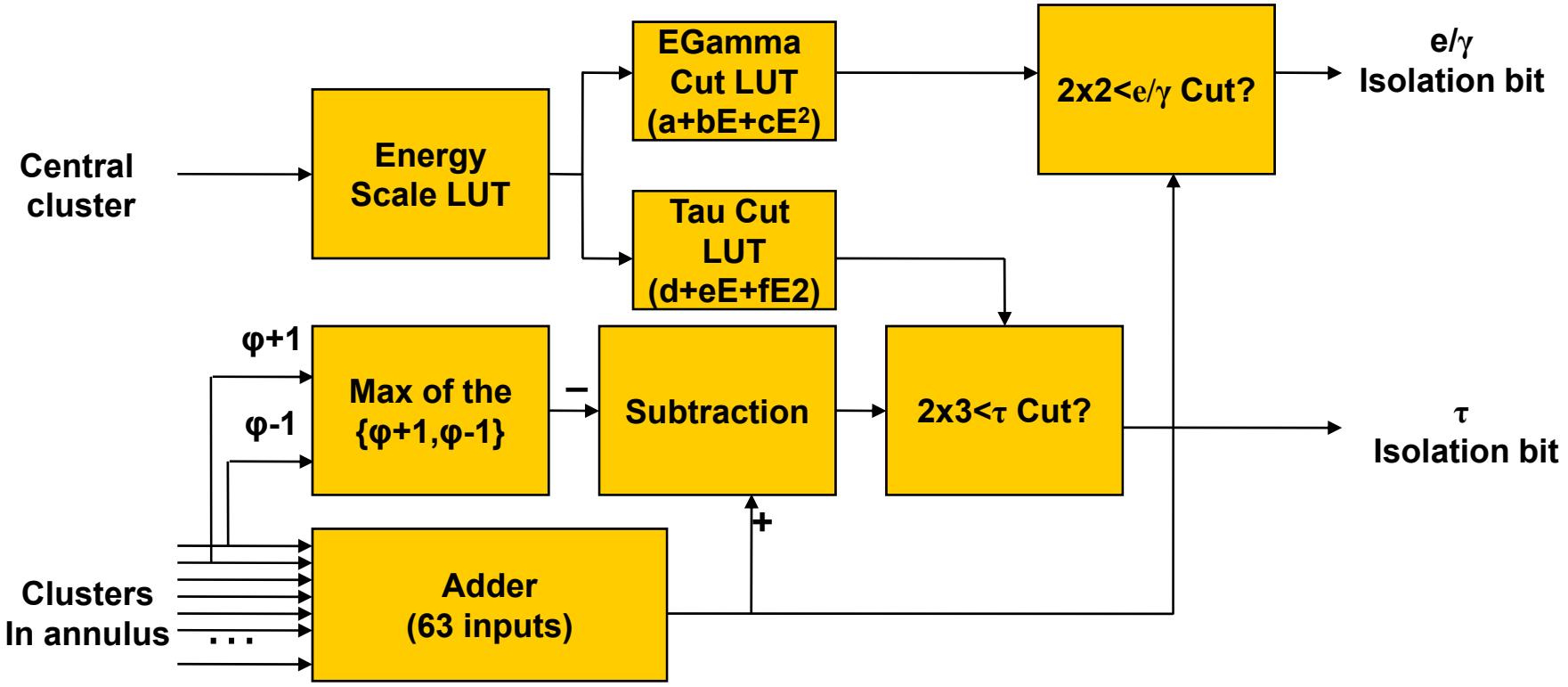
Cluster Isolation

- Two isolation approaches
  - Absolute Isolation
    - Require low Energy deposits around the object of interest
  - Relative Isolation
    - Require insignificant energy deposits compared to the energy of the object of interest
- Sliding isolation cuts
  - Isolation should be tight only in low Et region
  - Isolation should be very loose where the rate is low (Higher Et)

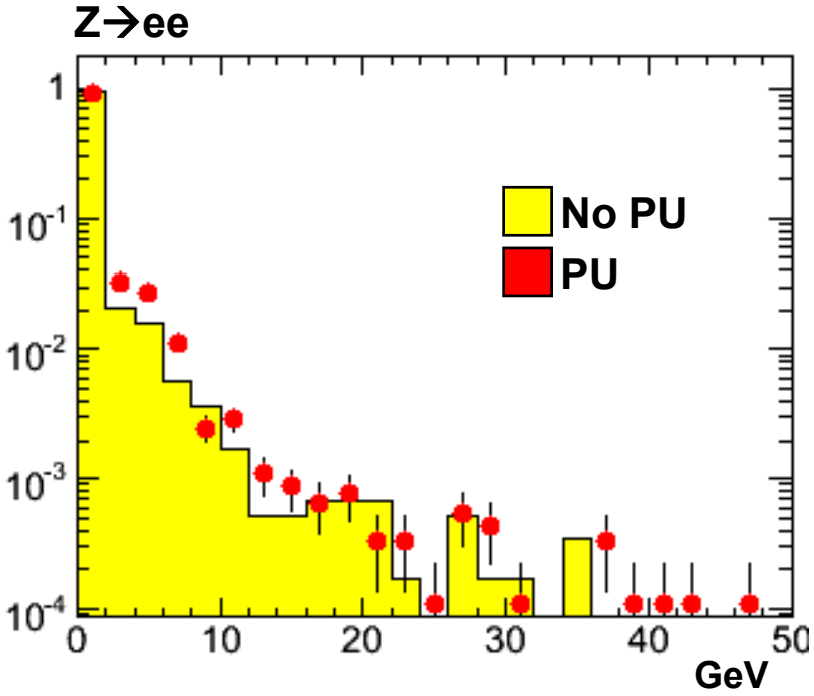


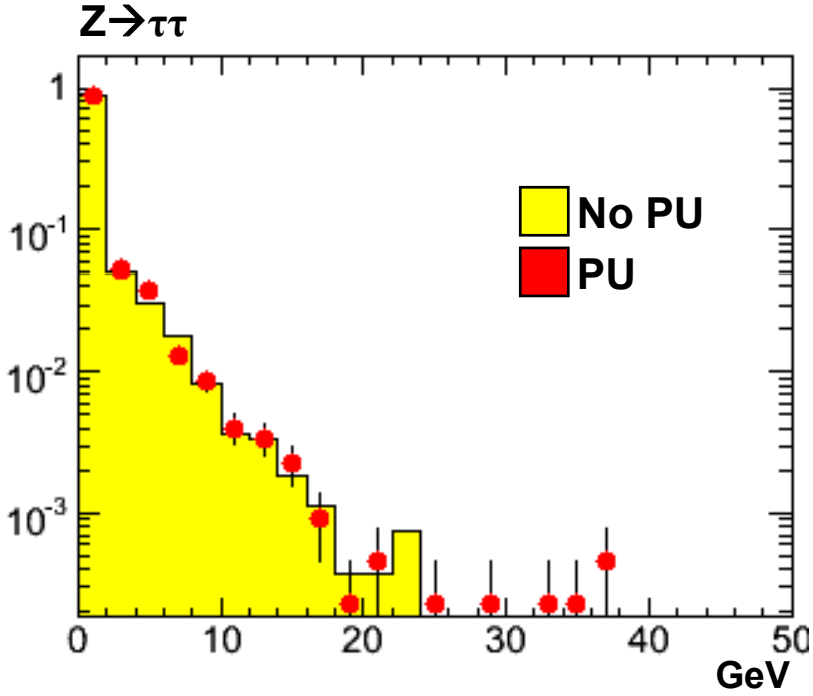
- Isolated Deposits
  - $Iso_{2x2} = \sum E$ (annulus)
  - $Iso_{2x3} = Iso2x2 - max\ \{E_{\varphi-1}, E_{\varphi+1}\}$
- For 2x3 isolation we used the maximum of the neighboring φ cluster
- Isolation Selection
  - $Iso_{2x2} < a + b\ E_{cluster} + c\ E_{cluster}^2$
  - $Iso_{2x3} < d + e\ E_{cluster} + f\ E_{cluster}^2$
- Different cuts for electron / tau isolation

Cluster Isolation Logic



Isolation Deposits





- The isolation distributions look very similar
  - This is due to the Activity thresholds and the overlap filter
  - Activity Thresholds: (E,H) = (1,3) GeV
  - Cluster Threshold: 3 GeV

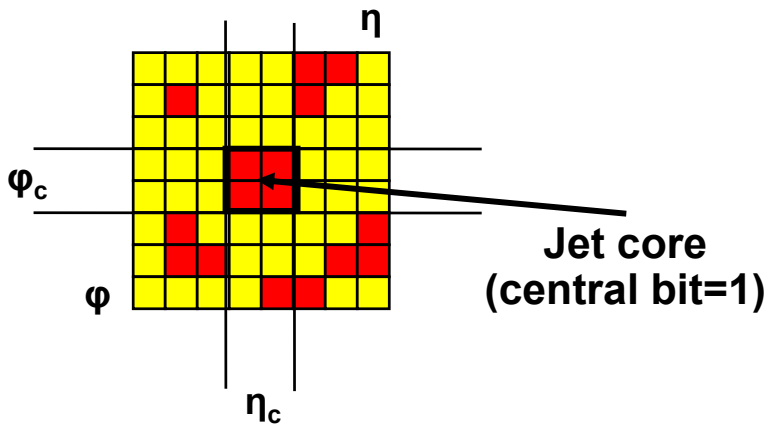
e/γ, τ identification

- After all previous steps, each cluster is described by 16 bits
  - Energy : 11 bits
  - Finegrain : 1 bit
  - e/γ: 1/bit
  - Central (local maximum) : 1 bit
  - 2x2 Isolation : 1 bit
  - 2x3 Isolation : 1 bit
- Single particle deposits are described by clusters that are not pruned (Central bit is set)
- Electrons/Photons
  - Central bit is set (Cluster is not pruned)
  - e/γ bit is set, finegrain veto is not set (e/γ-like cluster)
- Isolated Electrons/Photons
  - Electron requirements AND (2x2 isolation bit set)
- Taus
  - Central bit is set (Cluster is not pruned)
  - 2x3 Isolation bit is set

Jet Reconstruction

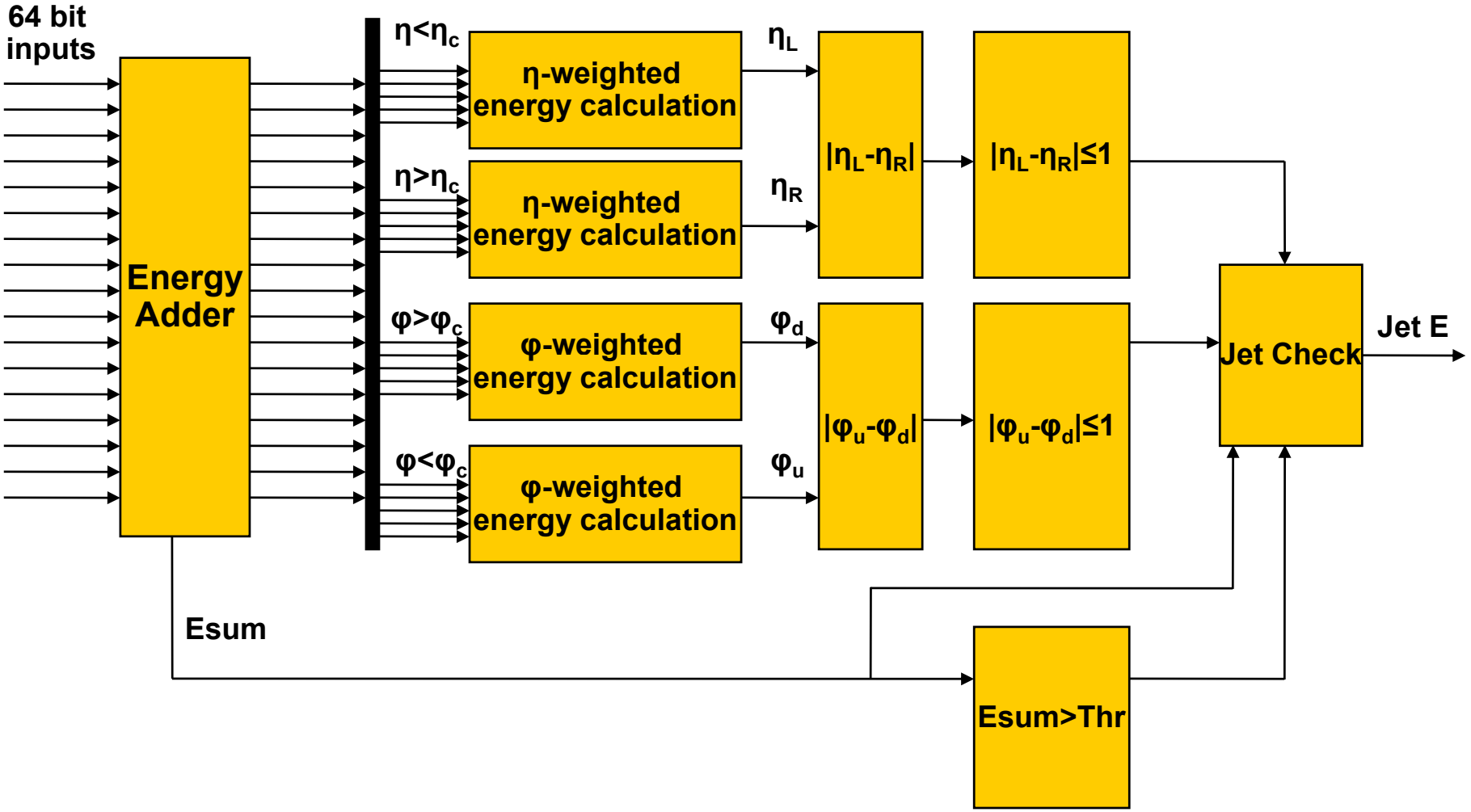
- Jets are reconstructed by summing energy around a local maximum cluster
- Require
  - The energy weighted position is inside the central cluster
  - Minimum jet energy
- Alternatives
  - Variable size is also possible
    - Split the jet region in zones and require energy cutoffs on each zone

Reconstruct jets in 8x8 regions



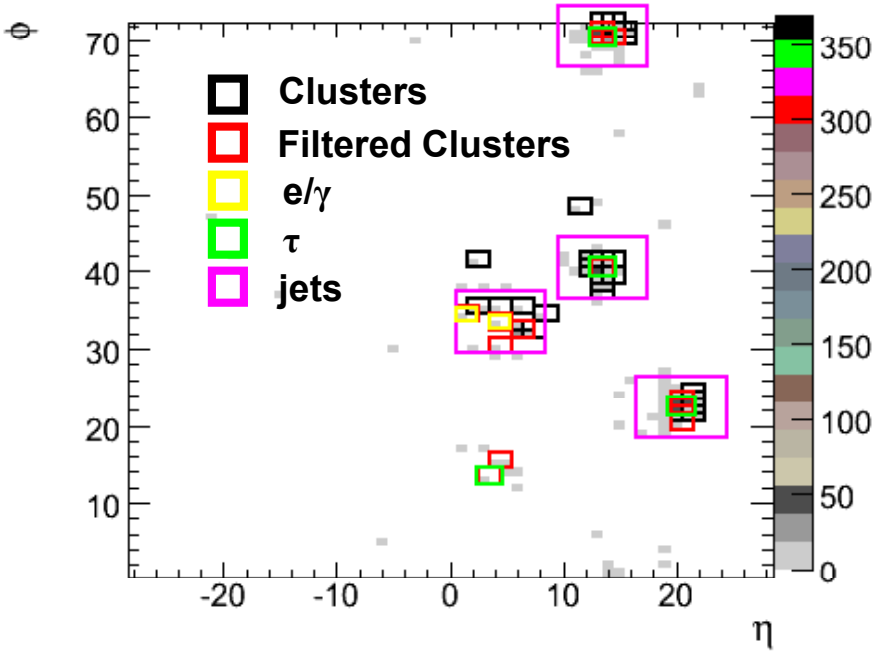
Require centered energy deposits

Jet reconstruction logic

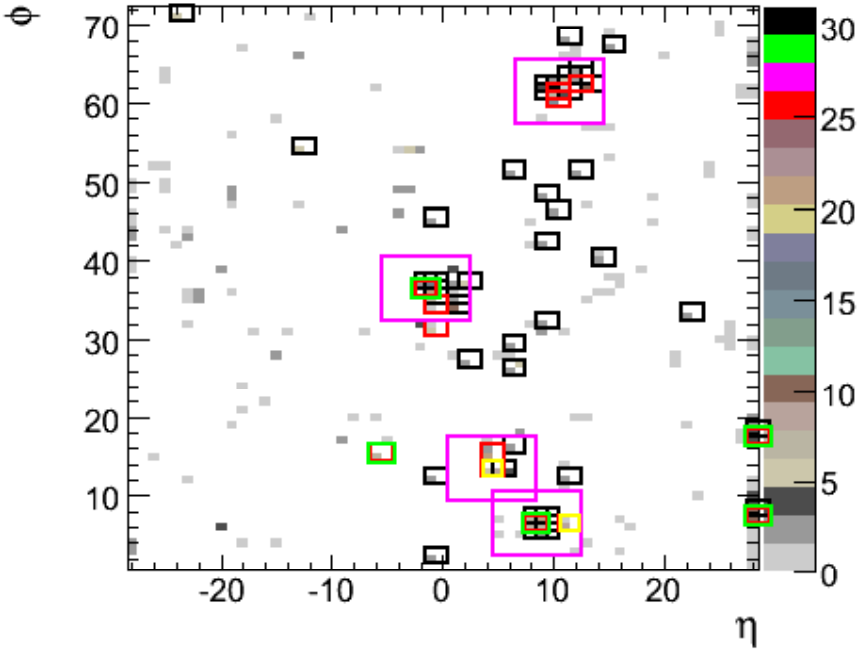


ttbar after full chain

TTbar – No PU



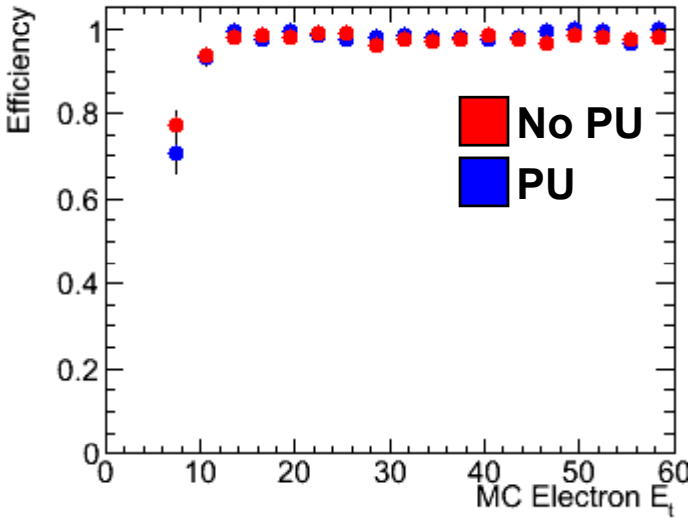
TTbar – PU



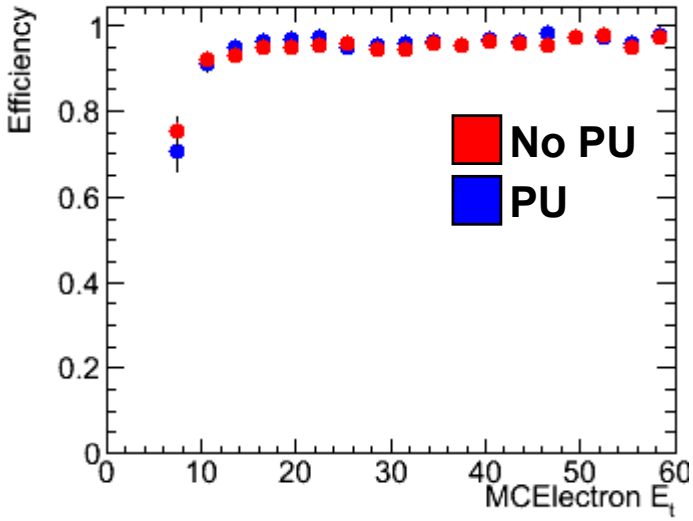
- Here the pattern recognition is depicted
- There are a lot of reconstructed candidates in those events but we trigger only on the four most energetic ones
- A lot of clusters in PU event but most of them do not pass the filter

Electron/Tau Efficiency

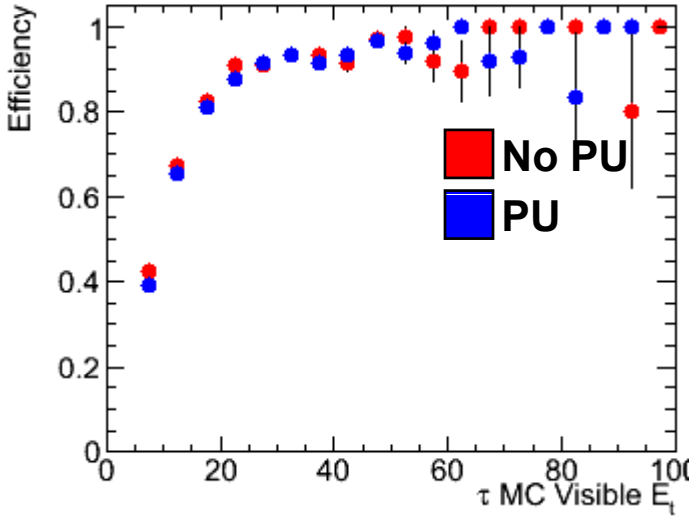
e/γ /Z→ee



Isolated e/γ /Z→ee



τ /Z→ττ

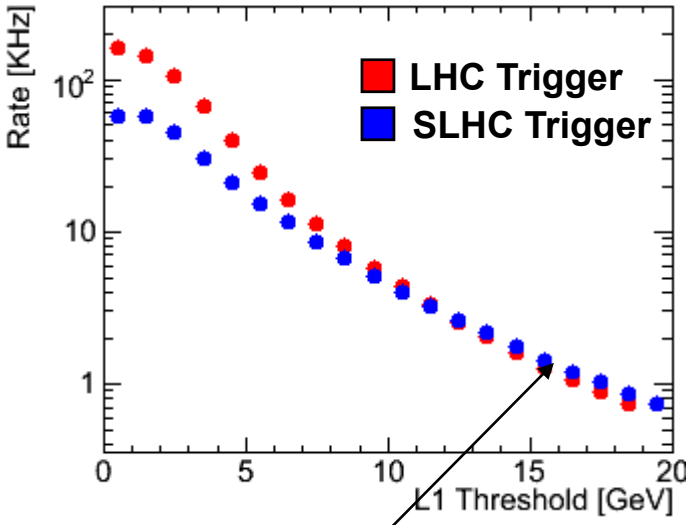


- **Preliminary results**
  - **Selection cuts not optimized yet**
  - **ie Isolation could relax at lower Et for taus**

Comparison with the standard trigger

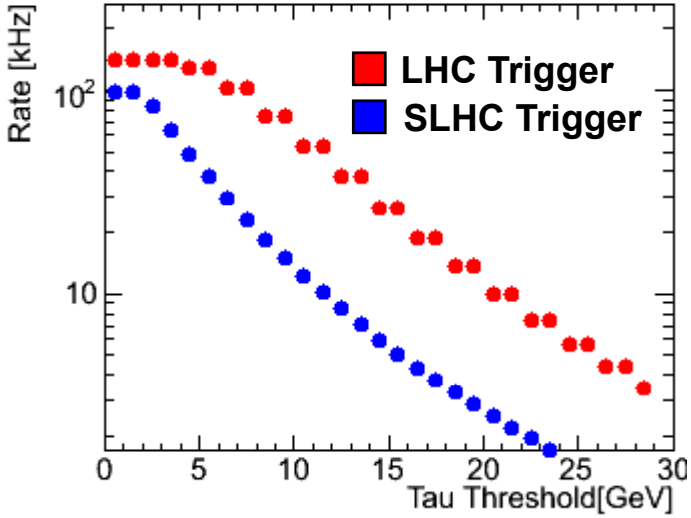
- Comparison with the standard trigger without energy corrections
- Benchmark Lumi :2E32 $cm^{-2}s^{-1}$
- Note:Both algorithms use uncorrected Et but for taus the energy thresholds are slightly different
  - The SLHC Trigger tau Et is ~5-10% lower than LHC Trigger tau Et

Isolated e/γ Trigger



At high Et the isolation in SLHC Trigger relaxes
So the rate slightly increases

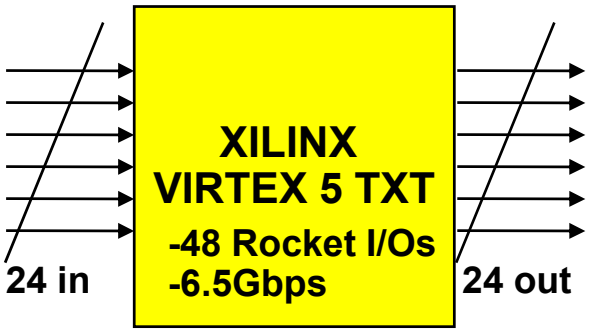
Single τ Trigger



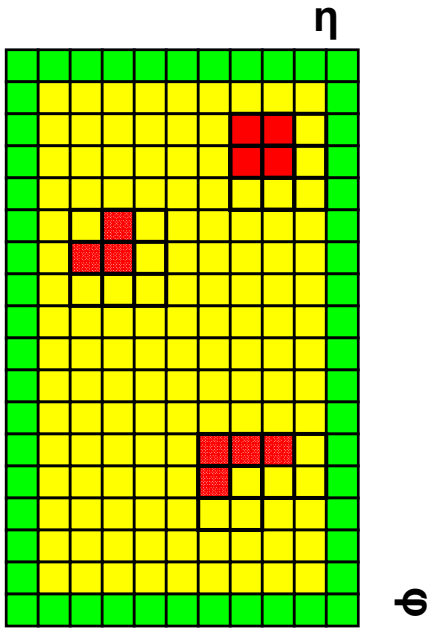
Significant improvement for taus !
The single Tau Threshold could be <1/2 the value we have now

Layout Example I (Clustering/Filtering)

- Clustering /Filtering algorithms have:
  - Number of Inputs = Number of outputs
- 24 Rocket I/Os can be used for input
  - One Rocket I/O can hold 9 Calorimeter TPG
  - That corresponds to 216 Calorimeter TPG input (17 bit)
  - Some bits are needed for Error correction
- 24 Rocket I/Os can be used for output
  - One rocket I/O can hold 10 clusters
  - That corresponds to maximum 240 Filtered Cluster output (14 bits)
- Optimal segmentation:
  - 8x16 towers / card (+ 1,2 border/overlap layers)
  - 36 cards for Clustering/Filtering



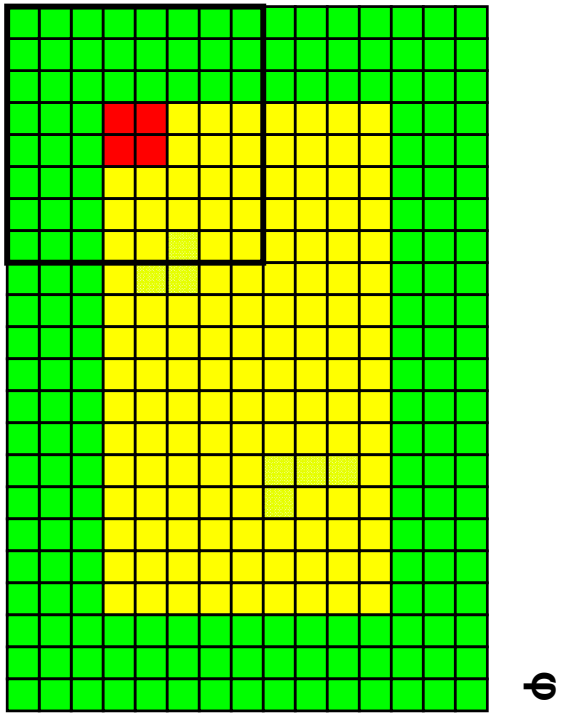
Clustering/Filtering layout



Layout Example II (Isolation/Particle ID/Jets)

- To perform jet reconstruction(8x8) on a 8x16 lattice, a card of 14x22 is needed (308 clusters) = 4310 bits
  - The output is smaller in this case
  - Assume maximum output / card = 25 objects (25 bits) = 625 bits
  - Number of I/O bits ~5000
  - 48 Rocket I/Os can handle 7800 bits
  - So jet reconstruction and isolation could be unified to one card
  - 10x10 /12x12 jets are also possible
- Summary Card(s)
  - Take as input the most energetic objects from each card
  - Take as input Tracker Trigger data
  - Separate objects by mapping tracker and calorimeter data
  - Sort the objects and output the most energetic ones to GT
- Restriction: Circuit logic resources

Isolation/Jets layout



Algorithm implementation studies in Wisconsin

- M.Schulte, K.Compton, B.Buchli, A. F-Farmahani, T.Gregerson, S.Naumov (ECE Department/UW)
- Tested some RCT ASIC algorithms in FPGA
  - Sorters, Adders (very high performance)
- Now Implementing and optimizing the clustering algorithm
  - Implementation of thresholds and pattern comparator
  - Comparison of LUT, Division implementation for electron ID
    - LUT is slower/larger than straightforward division implementation (but can implement the most general function)
      - 20 bit LUT:~380 MHz implemented at Block RAMs / 320 MHz on FPGA LUTS @ 6ns [7% of the LUTs]
      - Alternative LUT sizes also under study
    - Straight forward division (E/(E+H))
      - 420 MHz [0.1% of the logic]

Conclusion

- Simulation of a set of SLHC Calorimeter trigger Algorithms is in place
- More studies and improvements on the way
  - Threshold/Cut optimization
  - Jet reconstruction alternatives
  - Performance of Calibration/ eta correction on cluster level
  - Studies of SLHC (Higher) PU
- Need to line up with Tracking Trigger Simulation
  - What will be the track position granularity in Calorimeter surface?
  - At which level , should we do the Calorimeter /Tracker Trigger combination
- We are looking towards the Hardware implementation & constraints