Optimization of the Cluster Finder of the STAR Forward Calorimeter System (FCS)

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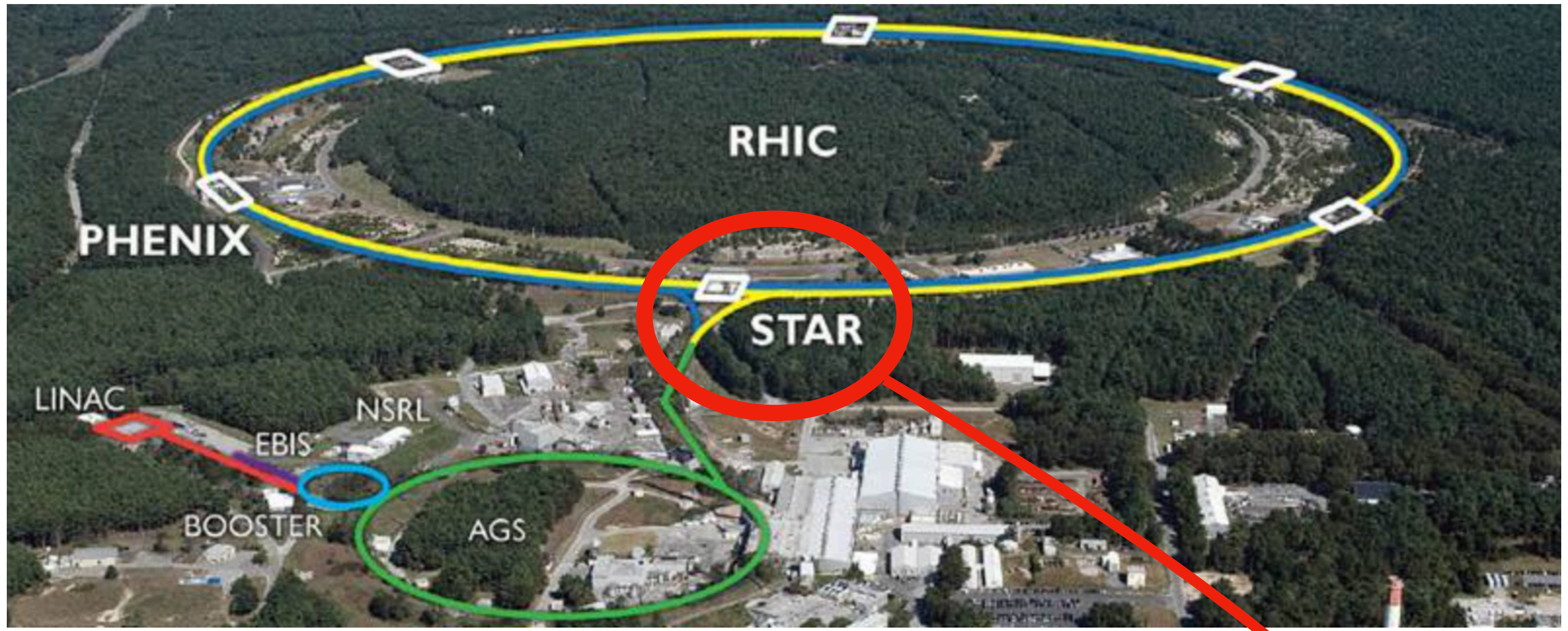
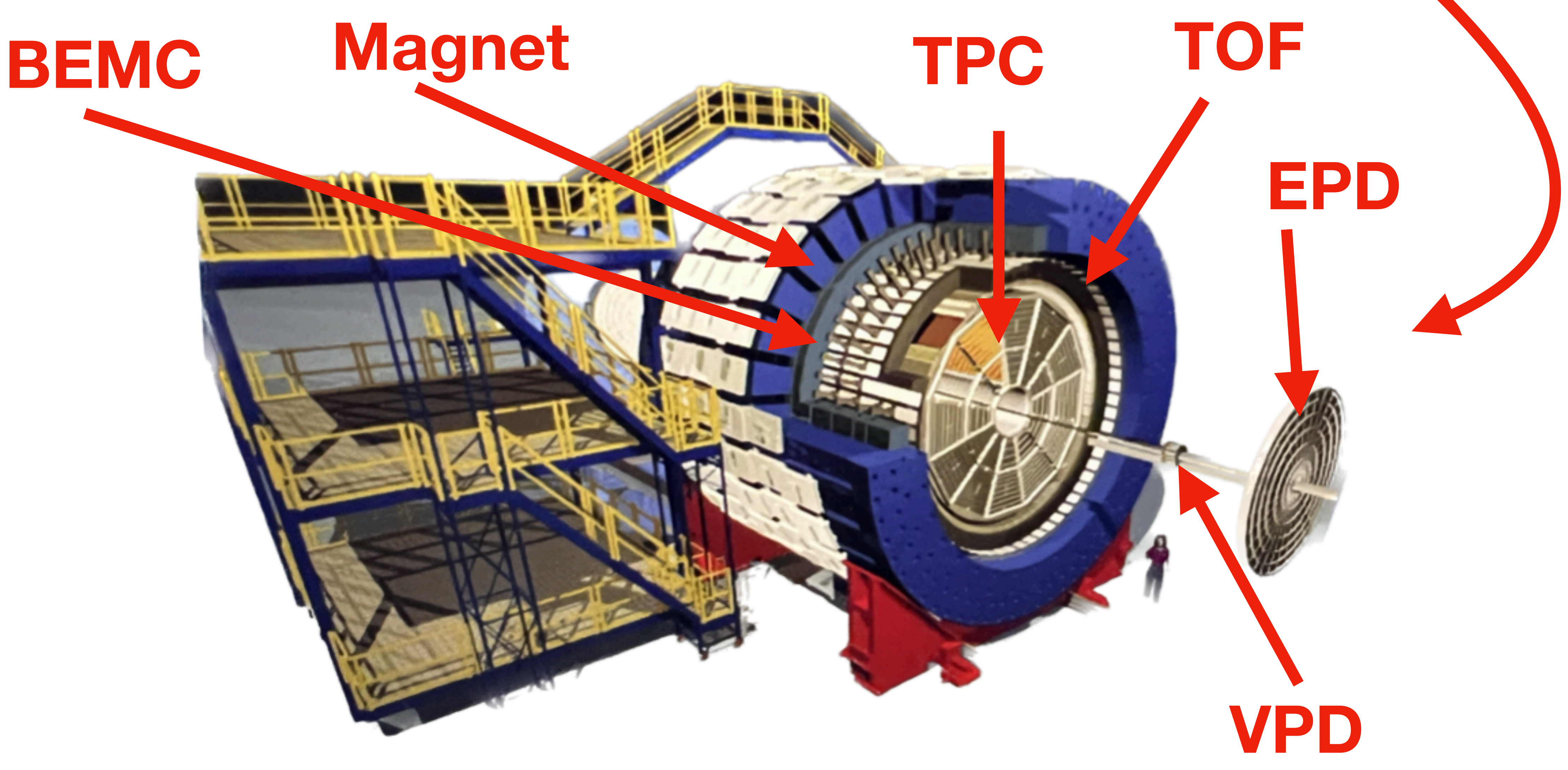
The Solenoid Tracker at RHIC (STAR)

- STAR is an experiment at the Relativistic Heavy Ion Collider (RHIC), who's focus is to explore the underlying structure of the proton through high energy collisions of polarized protons and heavy ions.

- STAR is a large acceptance detector with several sub-detectors that are designed to reconstruct the energy and momentum of the remnants of the collision.



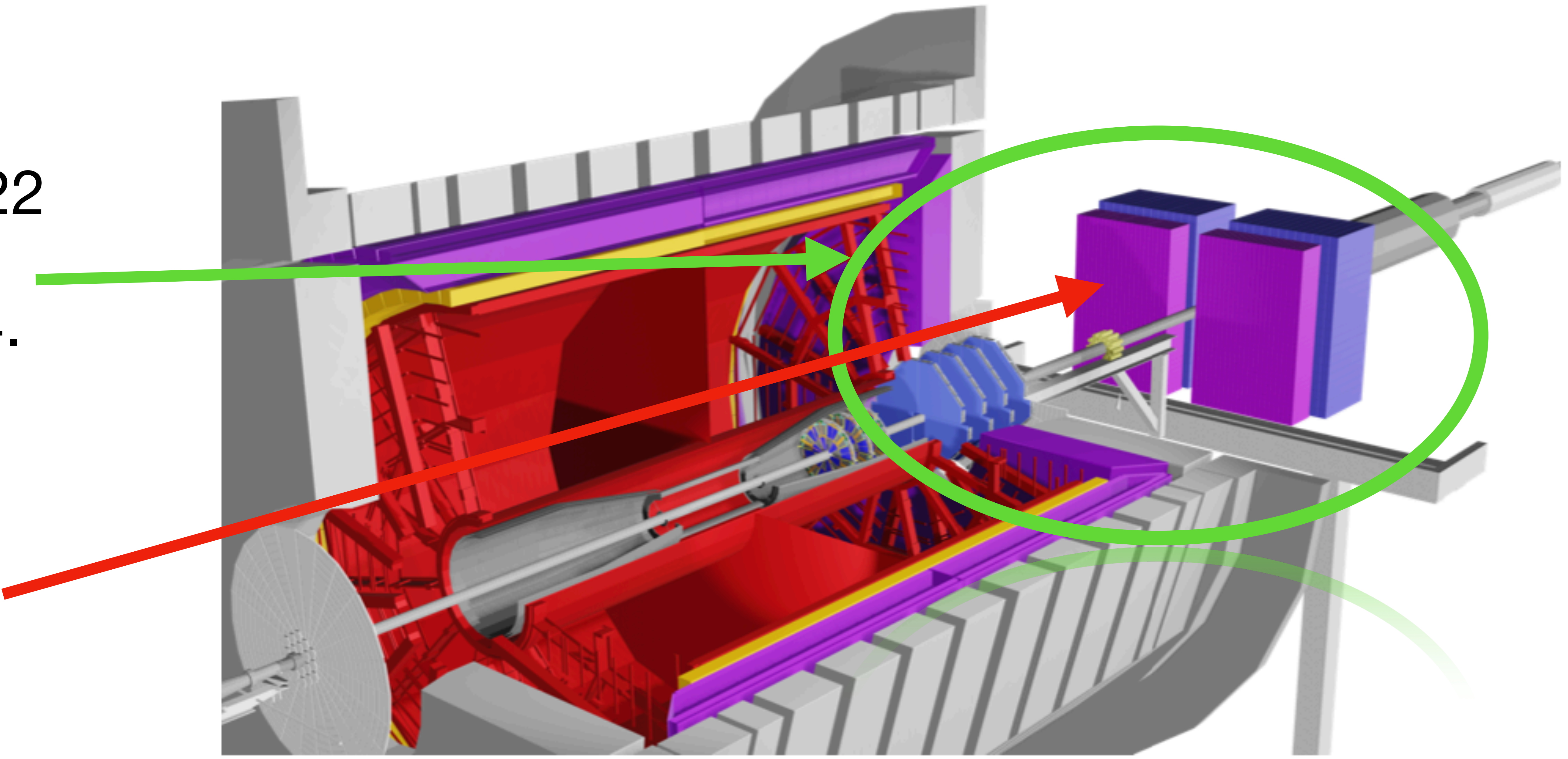
RHIC at Brookhaven National Lab (BNL)



The STAR Experiment at RHIC

Extending STAR Through the Forward Upgrade

- Since the TPC upgrade, STAR has had full tracking and electromagnetic calorimeter coverage at mid-rapidity (-1 <eta < 1.5).
- A new forward upgrade was installed for the 2022 run that extended, for the first time at STAR, tracking + calorimeter coverage to 2.5 < eta < 4.
- The Forward Calorimeter System (FCS) includes both a sampling Electromagnetic Calorimeter (ECal) (Fe/Si) and a sampling Hadronic Calorimeter (HCal)(Pb/Si).
- The forward upgrade will allow for full jet reconstruction and facilitate measurements of proton structure and gluon dynamics at very low (~10^{-4}) and high x.



Forward Upgrade at STAR

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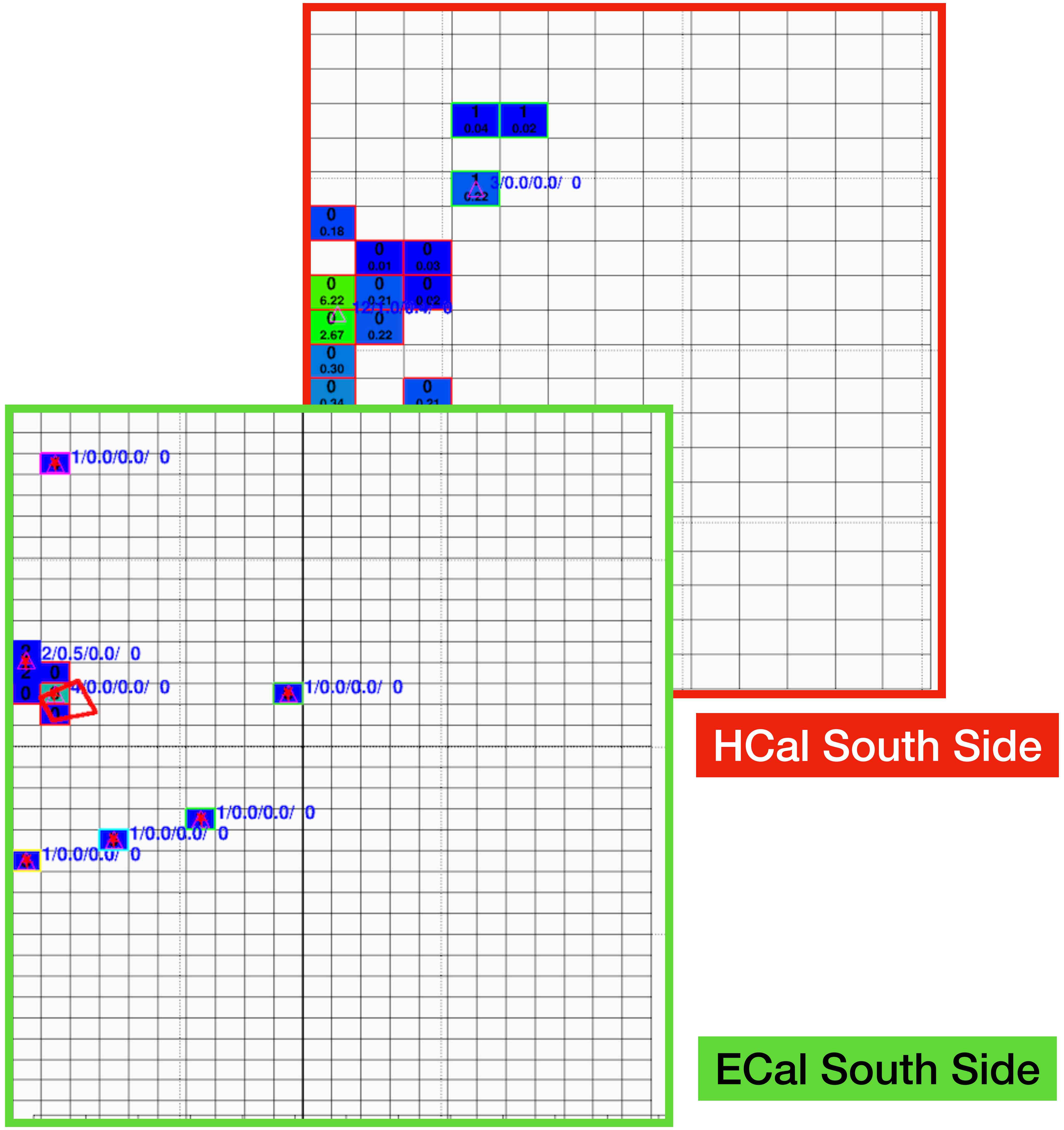
Particle Reconstruction Through Cluster Reconstruction

- As particles interact with the calorimeters they deposit energy via electromagnetic and hadronic showers. A clustering algorithm collects these deposits to reconstruct the energy of the particle.

- The ECal and HCal both consist of several hundred towers covering an area 3 m x 2 m. A tower of the ECal consist of 5.52 x 5.52 cm while a HCal tower 10 x 10 cm.



Simulated Event Display for a single π^+ at 15 GeV on the south side of the ECal and HCal.

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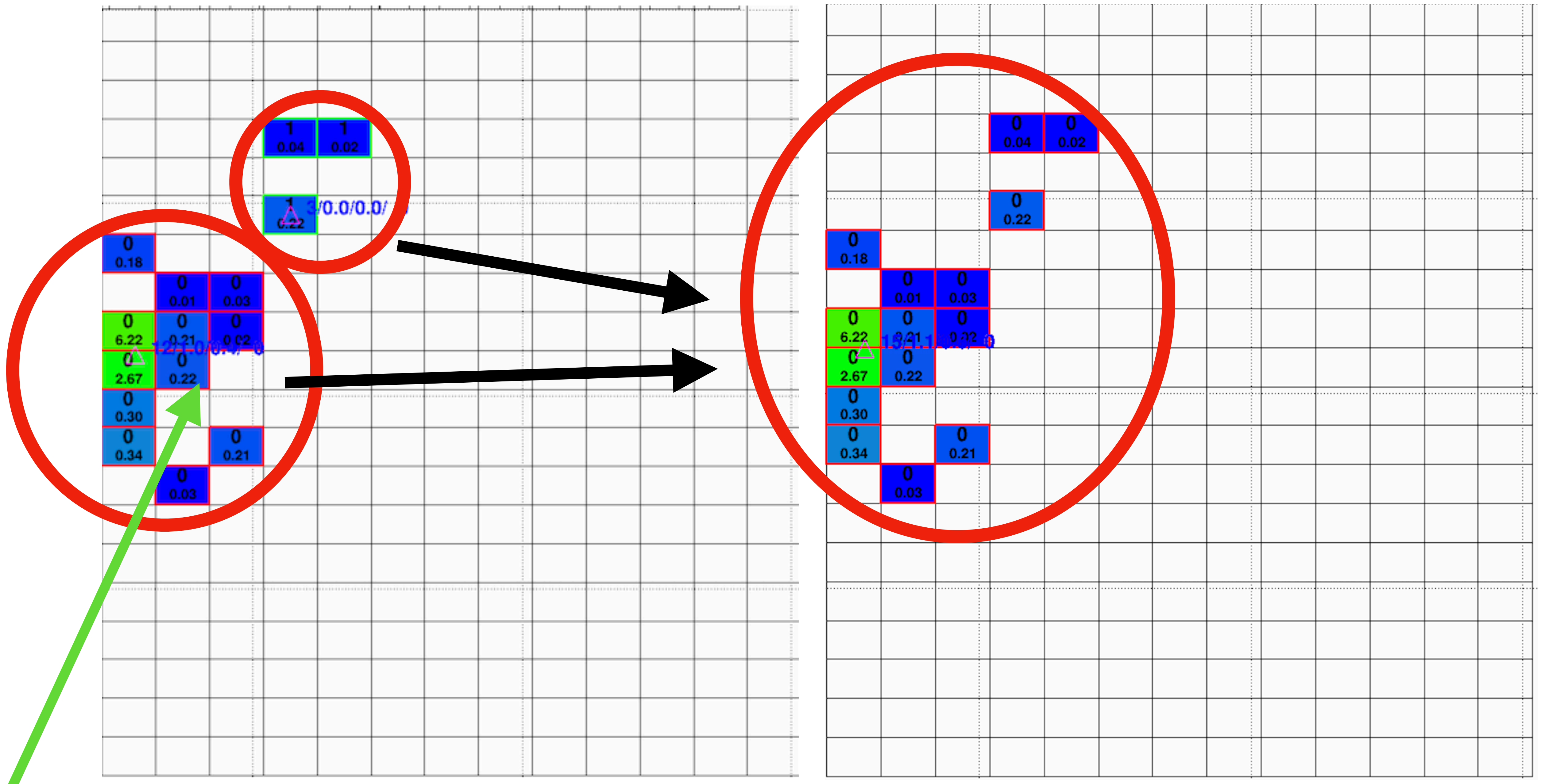
How the Cluster Finder Algorithm Works

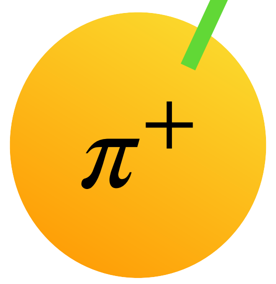
- The cluster algorithm makes use of two important parameters.

  1) A tower energy threshold - determines if a tower should be consider for cluster reconstruction. (**mTowerEThreshod**)

  2) Neighbor Distance - determines if a nearby tower should be added to an existing cluster based on proximity. (**mNeighborDistance**)

- In order to optimize each of these parameters we used simulated single particle and multi-particles events.



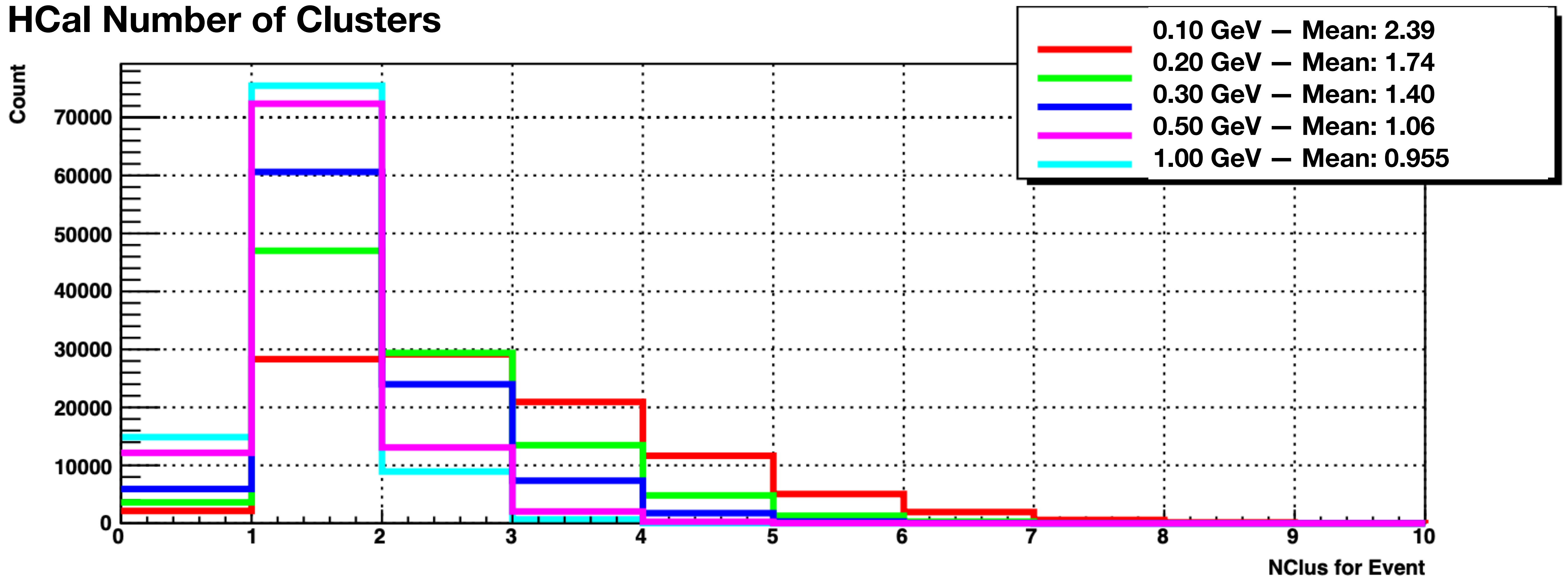


Event Display for a single π^+ at 15 GeV of HCal at neighborDistance$_{HCal} = 2.01$

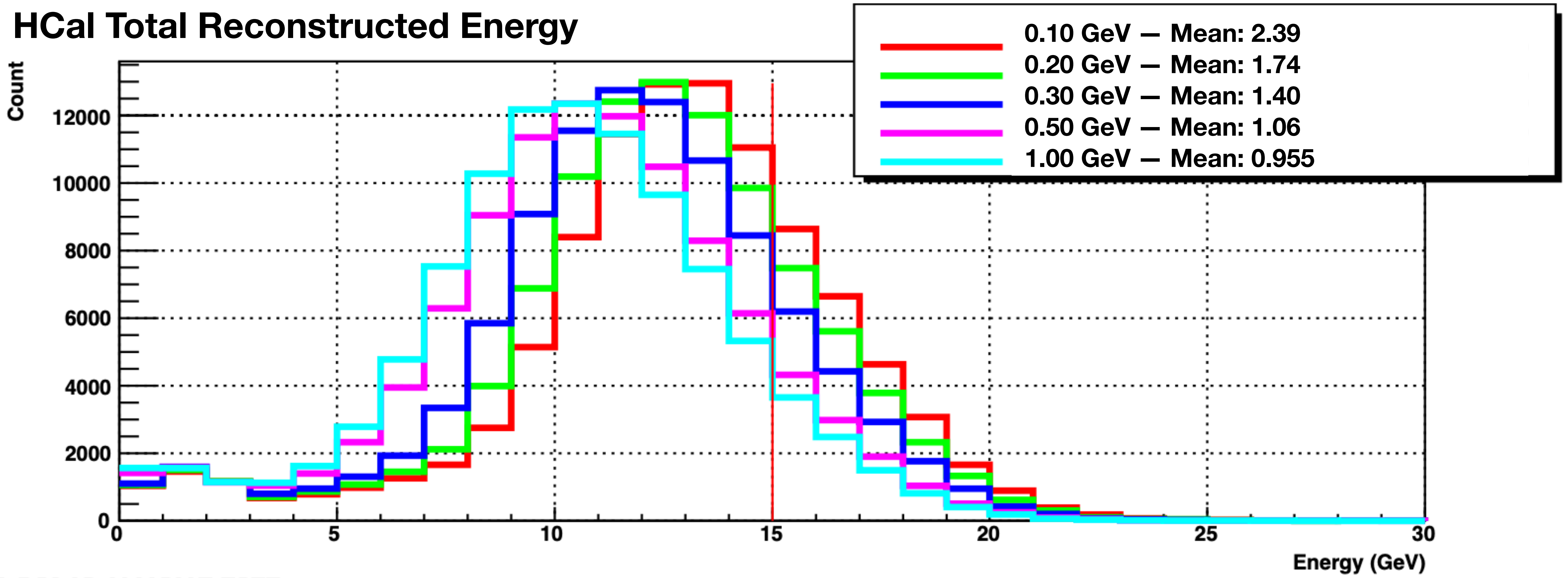
Event Display for a single π^+ at 15 GeV of HCal at neighborDistance$_{HCal} = 4.25$

Tuning the Energy Threshold Through Single Particle Events

- Single particle events were used to optimize the tower energy threshold parameter (**mTowerEThreshod)**
- Higher energy threshold lead to more single cluster events.
- However, higher thresholds reduce the overall energy of the reconstructed particle and increase the number of events where no clusters are found.
- Balancing these two factors lead us to choose,
  mTowerEThreshold_ECal = 0.1 GeV
  mTowerEThreshold_HCal = 0.2 GeV



Number of Cluster per Event for single π^+ at 15 GeV of HCal with mTowerEThreshod_HCal



Total Event Energy Reconstruction From Clusters per Event for single π^+ at 15 GeV of HCal with mTowerEThreshod_HCal

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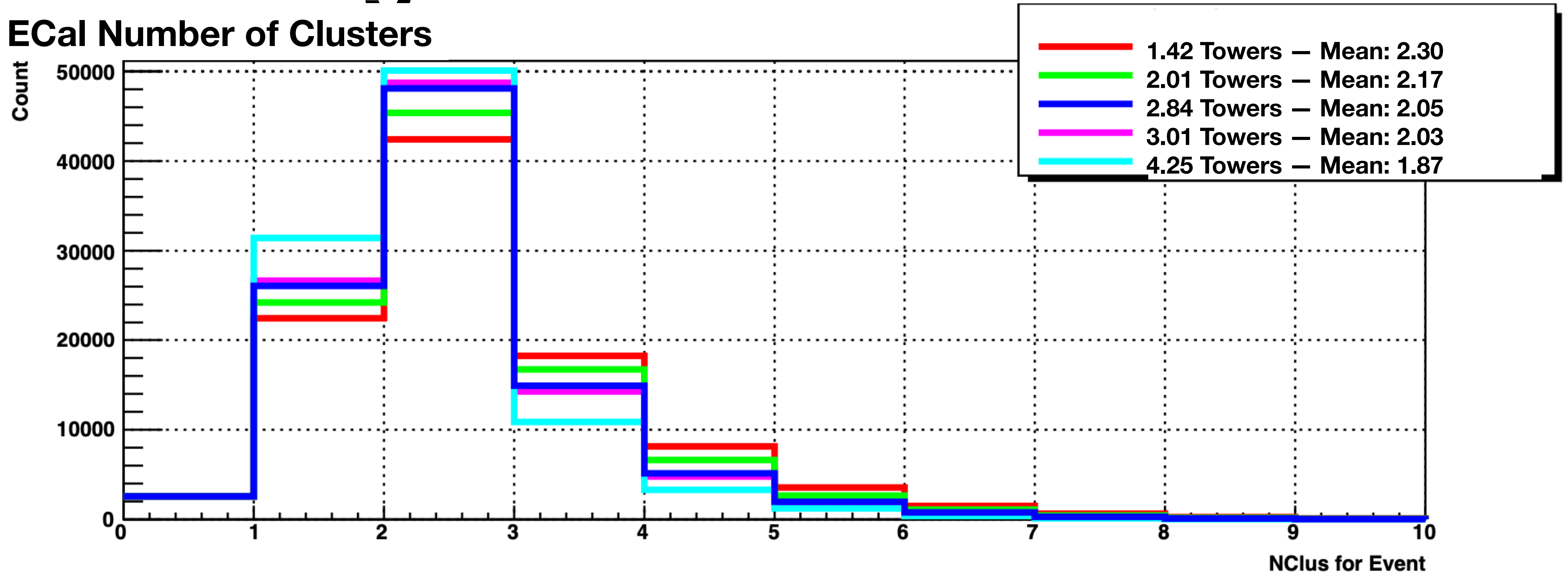
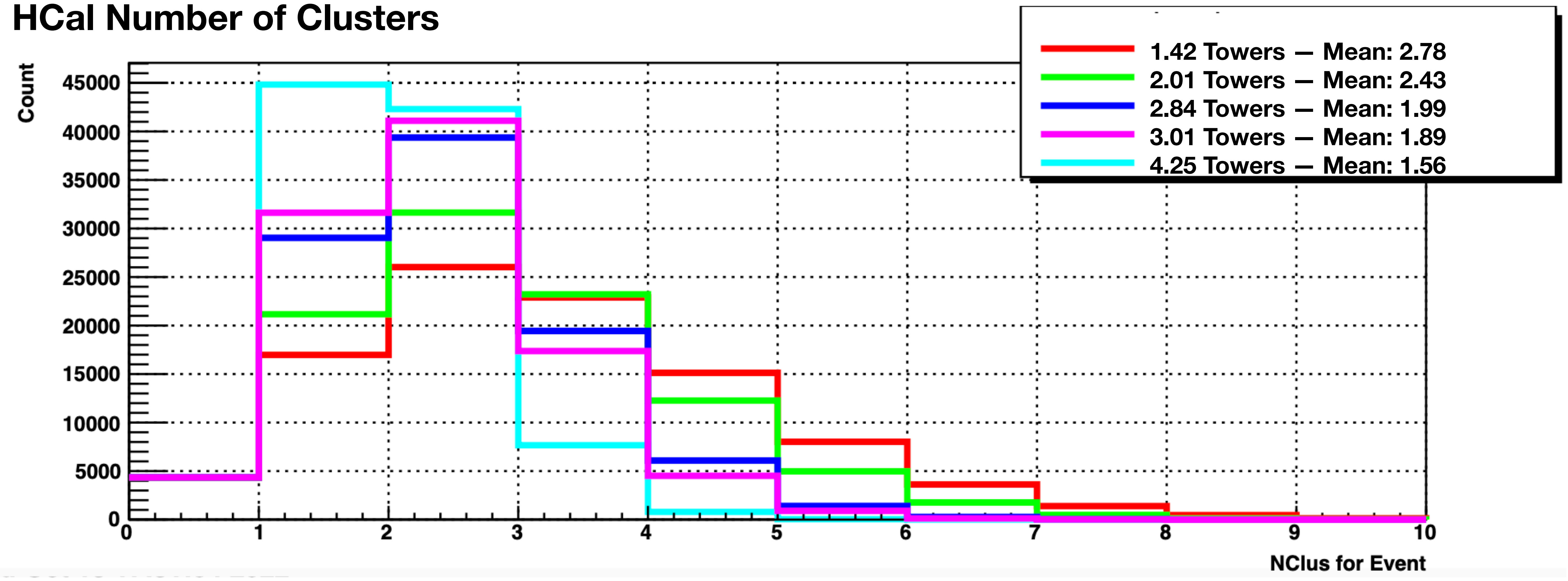
Tuning the Neighbor Distance Through Two-Particle Events

- To optimize the neighbor distance (**mNeighborDistance**) we focused on multi-particle events
- Need to optimize number of clusters reconstruction for two clusters.
- Minimize multi-particle energy contribution to a single cluster.
- The neighbor distance has little effect on ECal, but it drastically changes HCal.



Number of Cluster per Event for Two π^+ at 15 GeV of ECal with mNeighborDistance_ECal



Number of Cluster per Event for Two π^+ at 15 GeV of HCal with mNeighborDistance_HCal

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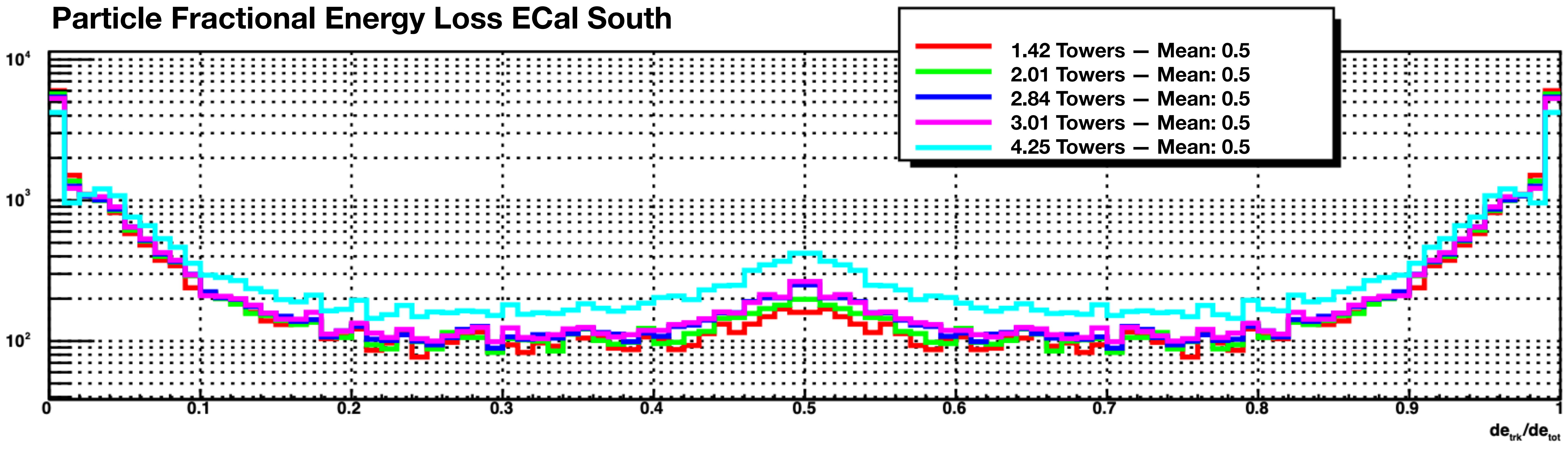
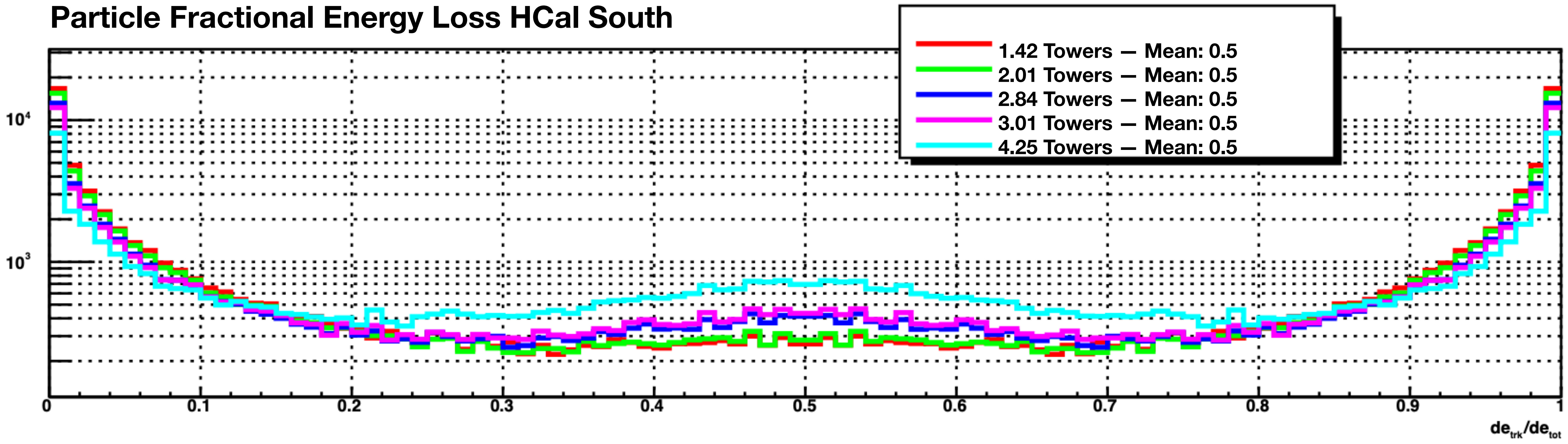
Tuning the Neighbor Distance Through Two-Particle Events

- Increasing **neighborDistance** on either of the Calorimeters increases multi-particle energy contribution.

- To determine overall fractional energy loss by any one particle we considered matching between an HCal cluster that was projected onto the Ecal and the nearest Ecal cluster.



Particle Fractional energy contribution to a cluster on ECal



Particle Fractional energy contribution to a cluster on HCal

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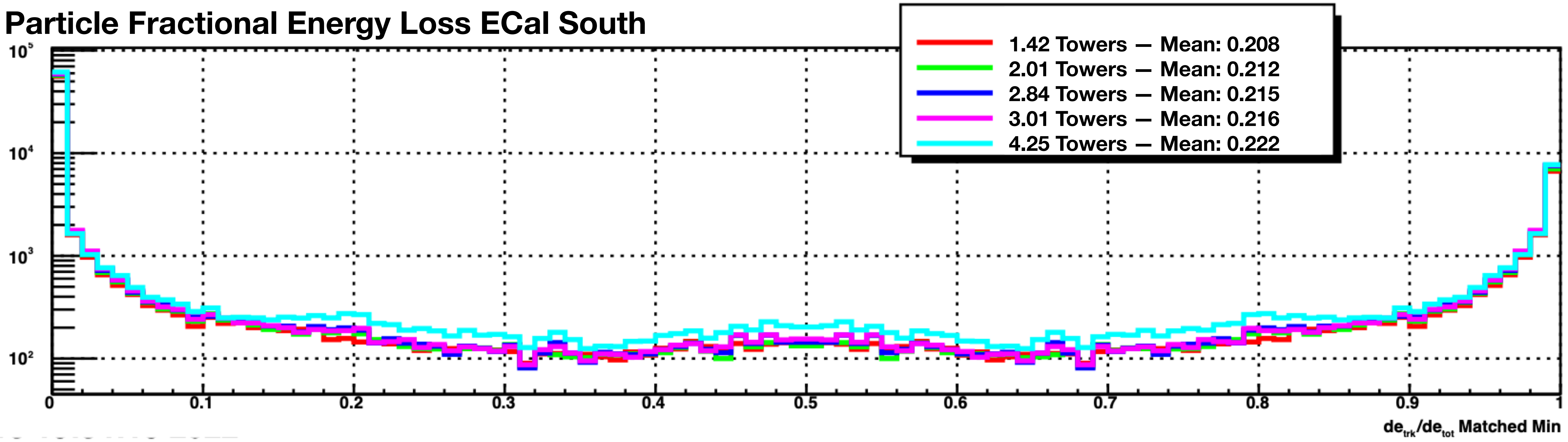
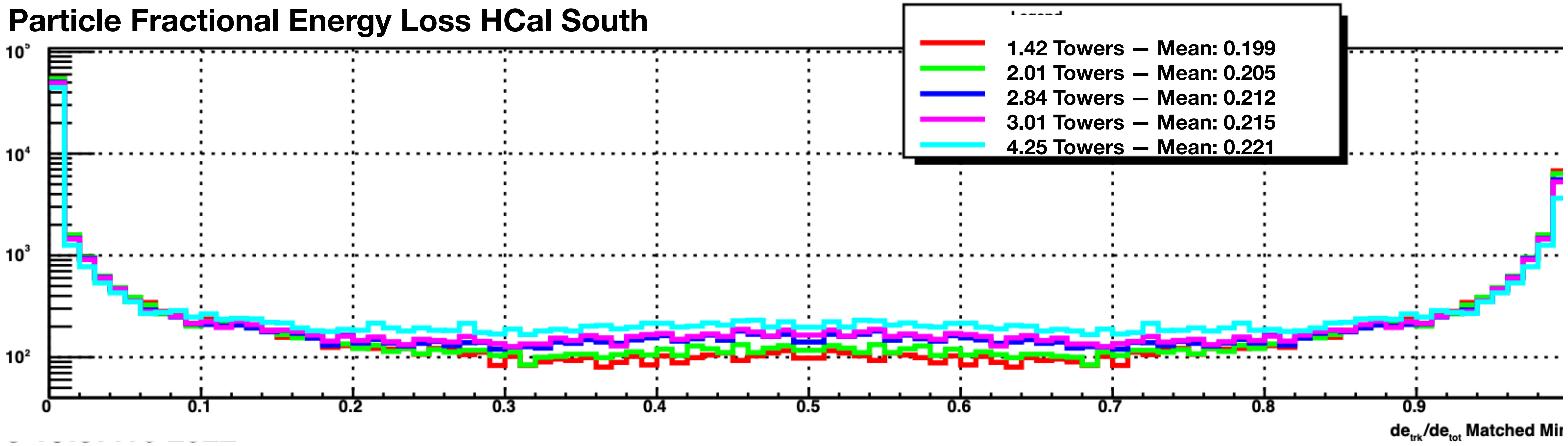
Tuning the Neighbor Distance Through Two-Particle Events

- When matching between clusters takes place the fractional energy contribution varies less.
- As a result we can choose between any of the intermediate value of the **neighborDistance**.
- We opted for the values that better reconstruct the number of clusters.
  mNeighborDistance_ECal = 2.84
  mNeighborDistance_HCal = 2.84



Particle Fractional energy contribution to a cluster on ECal with drCut = 15 cm



Particle Fractional energy contribution to a cluster on HCal with drCut = 15 cm

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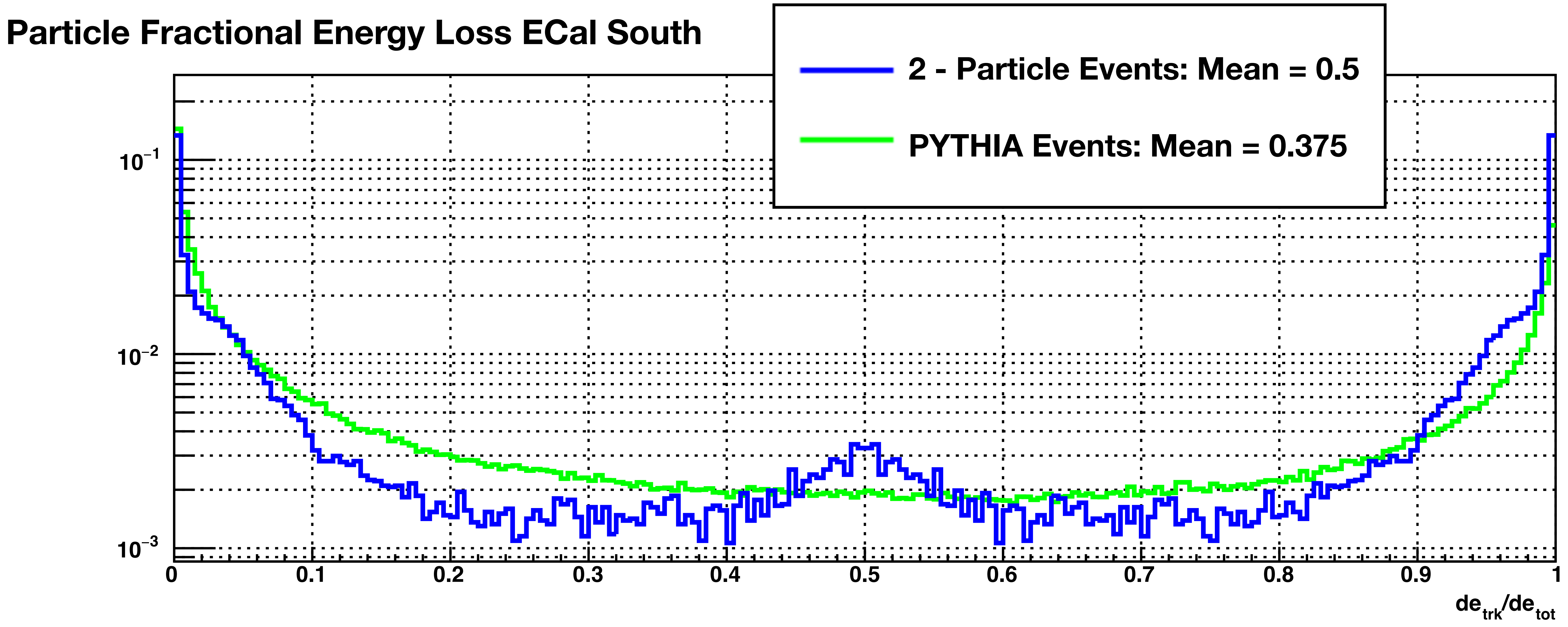
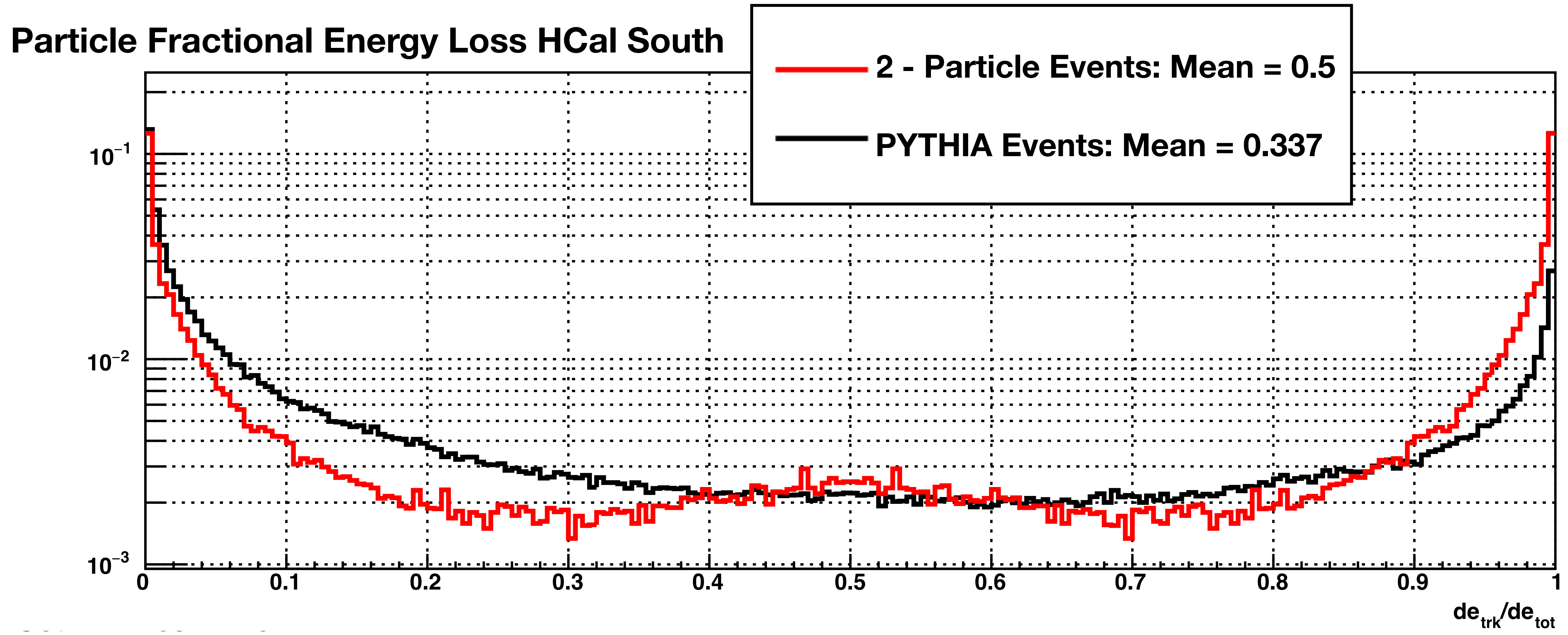
Comparing Multi-Particle Event to Full Simulated Particle Collisions at $\sqrt{s} = 510$ GeV

- Optional Cluster Finder Parameters:
  mTowerEThreshold_ECal=.1
  mTowerEThreshold_HCal=.2
  mNeighborDistance_ECal=2.84
  mNeighborDistance_HCal =2.84

- Comparison of the fractional energy contribution of a particle from a full simulated PYTHIA pp collision @ $\sqrt{S} = 500$ GeV and a two particle events of π^{+} at 15 GeV yields similar results.

- PYTHIA multi particle events in peak at .5 for 2 particle simulations are smeared out, but peaks at 1 and 0 are maintained, indicating cluster finder is performing well, even in more realistic multi-particle events.





Conclusions

- The newly installed STAR forward upgrade provides tracking and calorimeter coverage in the forward region, providing access to both low and high momentum fraction x.

- Simulated single and double pion events were used to optimize cluster parameters.

- The optimized cluster finder appears to work well in more realistic events simulated with full PYTHIA.

- Next Steps

1) Investigate a modified cluster finder with a higher threshold for seed towers and lower threshold for nearby towers.

2) Run cluster finder over pp collision data taken in Run 22