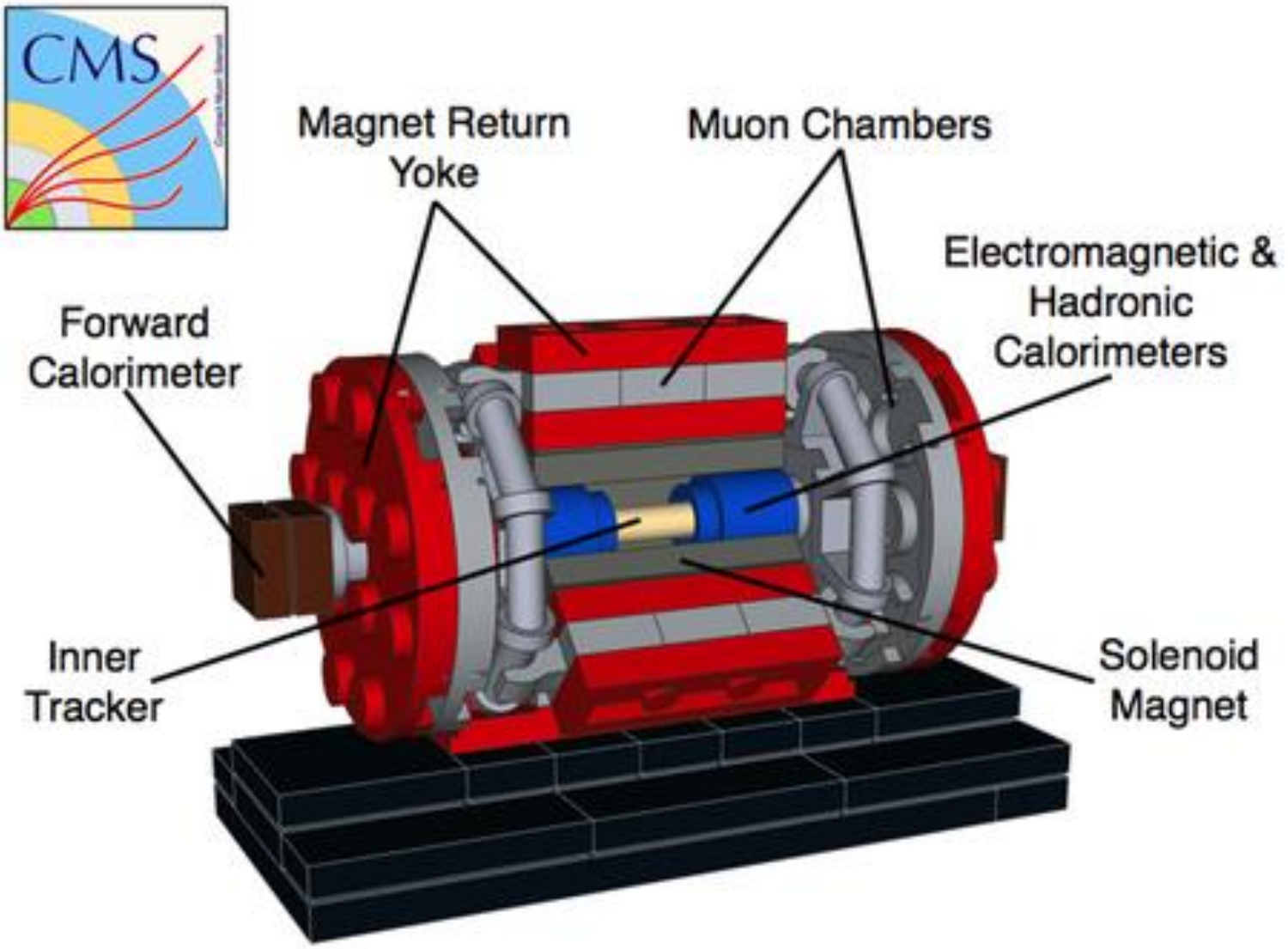
Particle Flow & Displays

CMSDAS 2023 EXERCISE

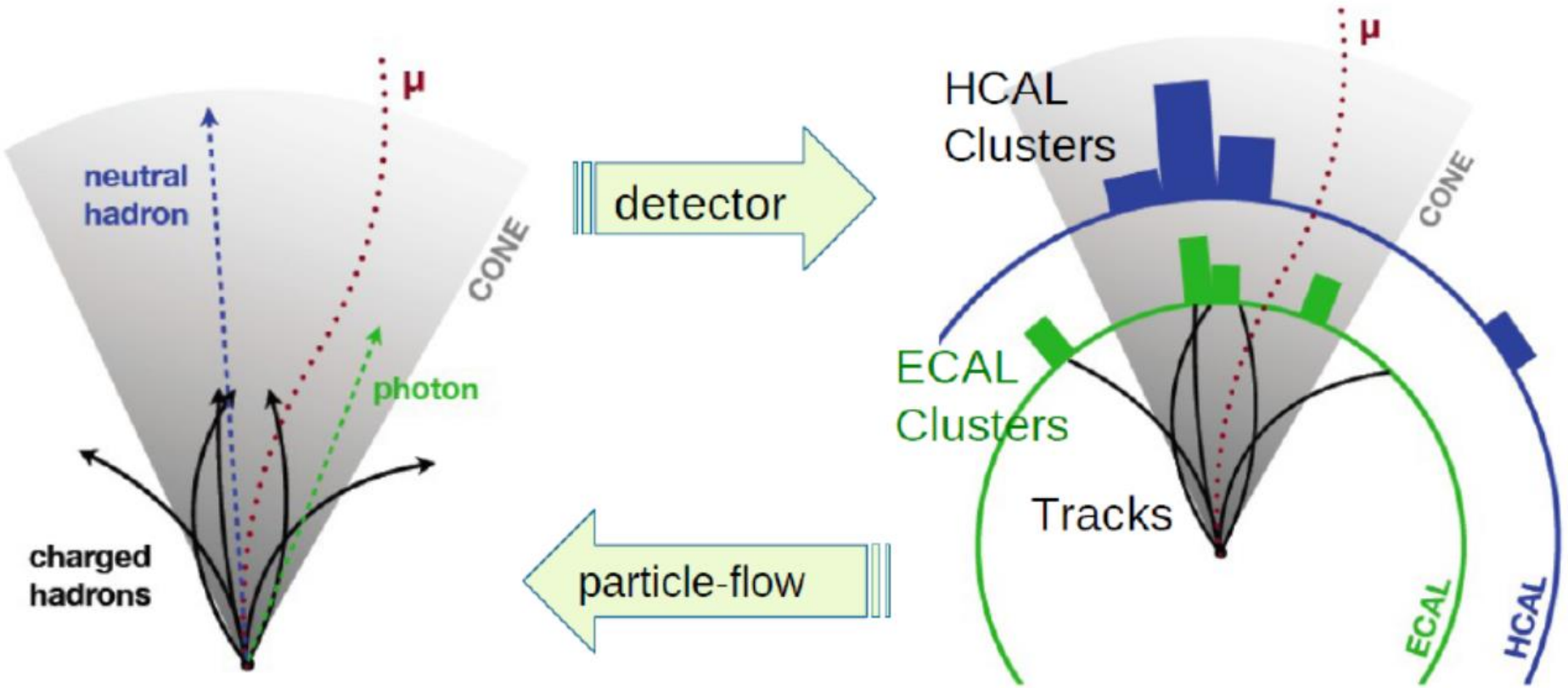
1/10/23

Making particles

Detecting particles



Particle Flow

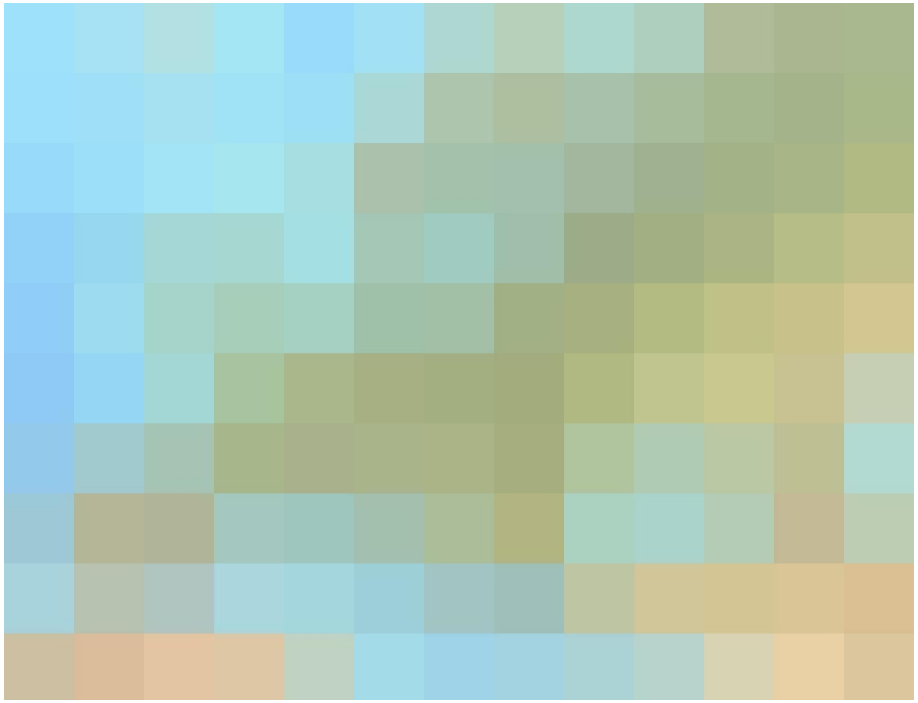


Particle Flow

- Your brain can de-pixelate too. Sometimes it's easy:

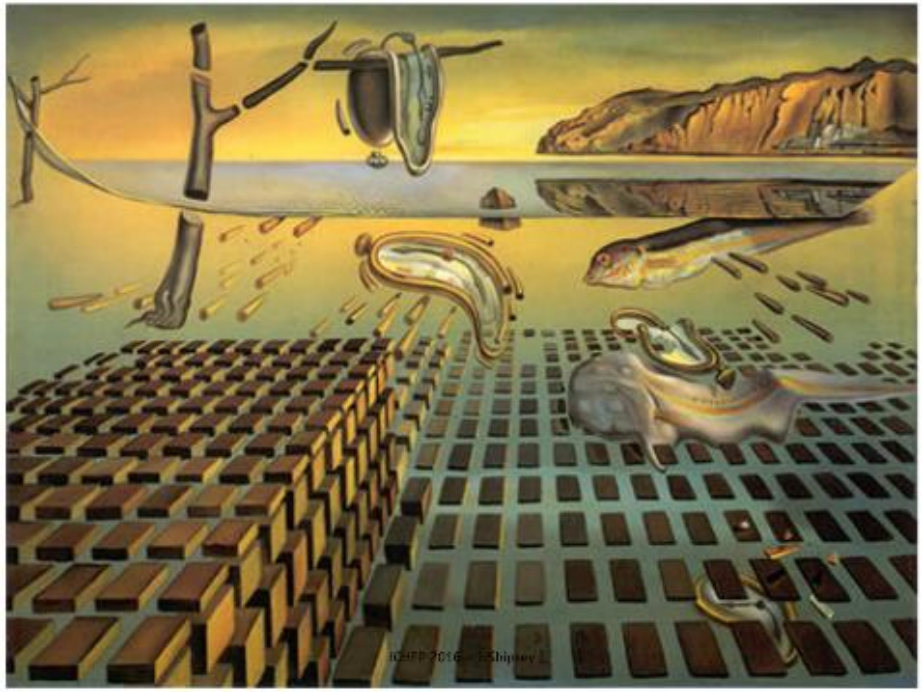
Particle Flow

- Your brain can de-pixelate too. Sometimes it's hard:



Particle Flow

- Your brain can de-pixelate too. Sometimes it's hard:
- Particle flow can deal with both cases



Visualizing CMS events

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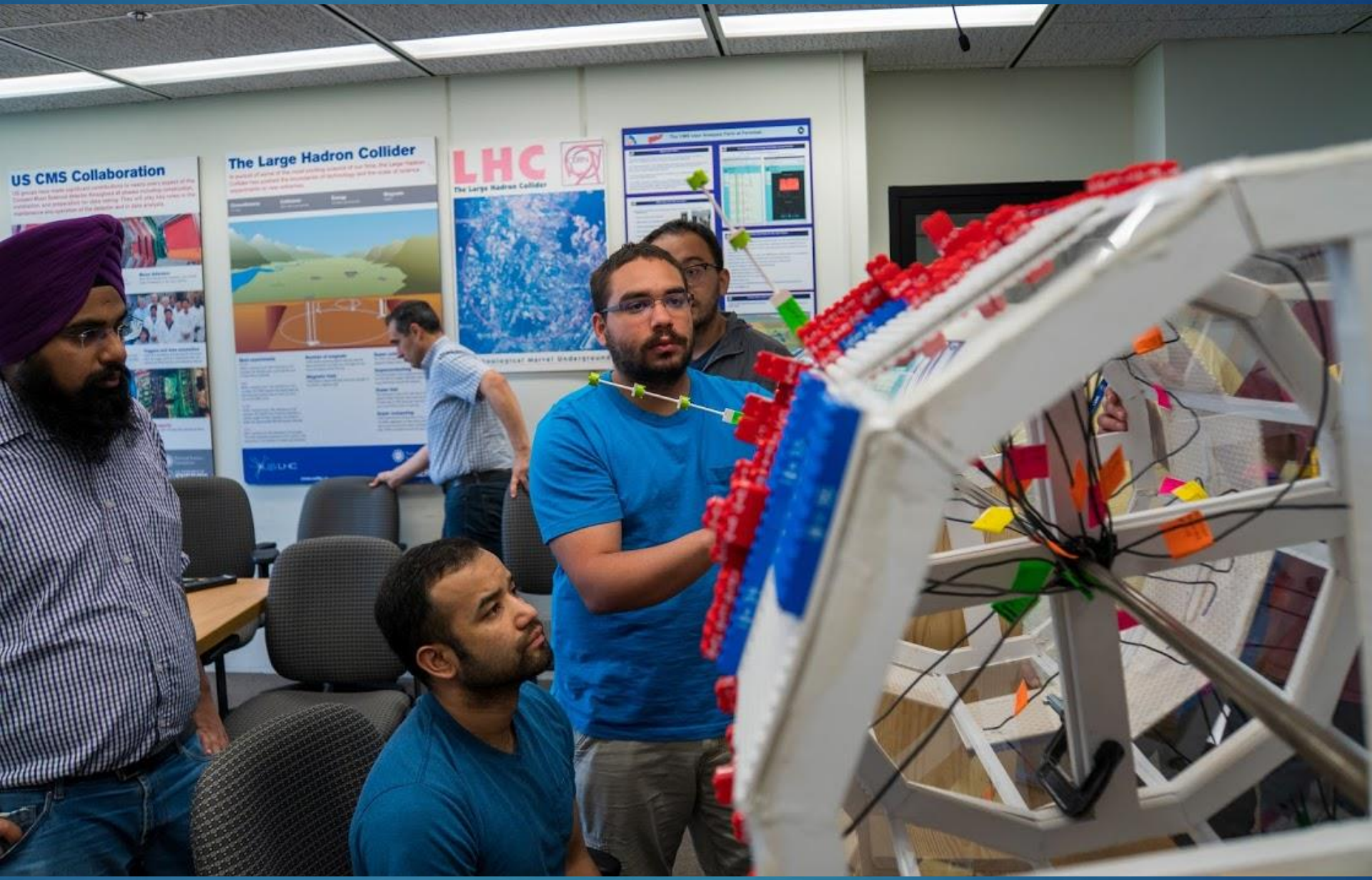
Visualizing CMS events



Visualizing CMS events

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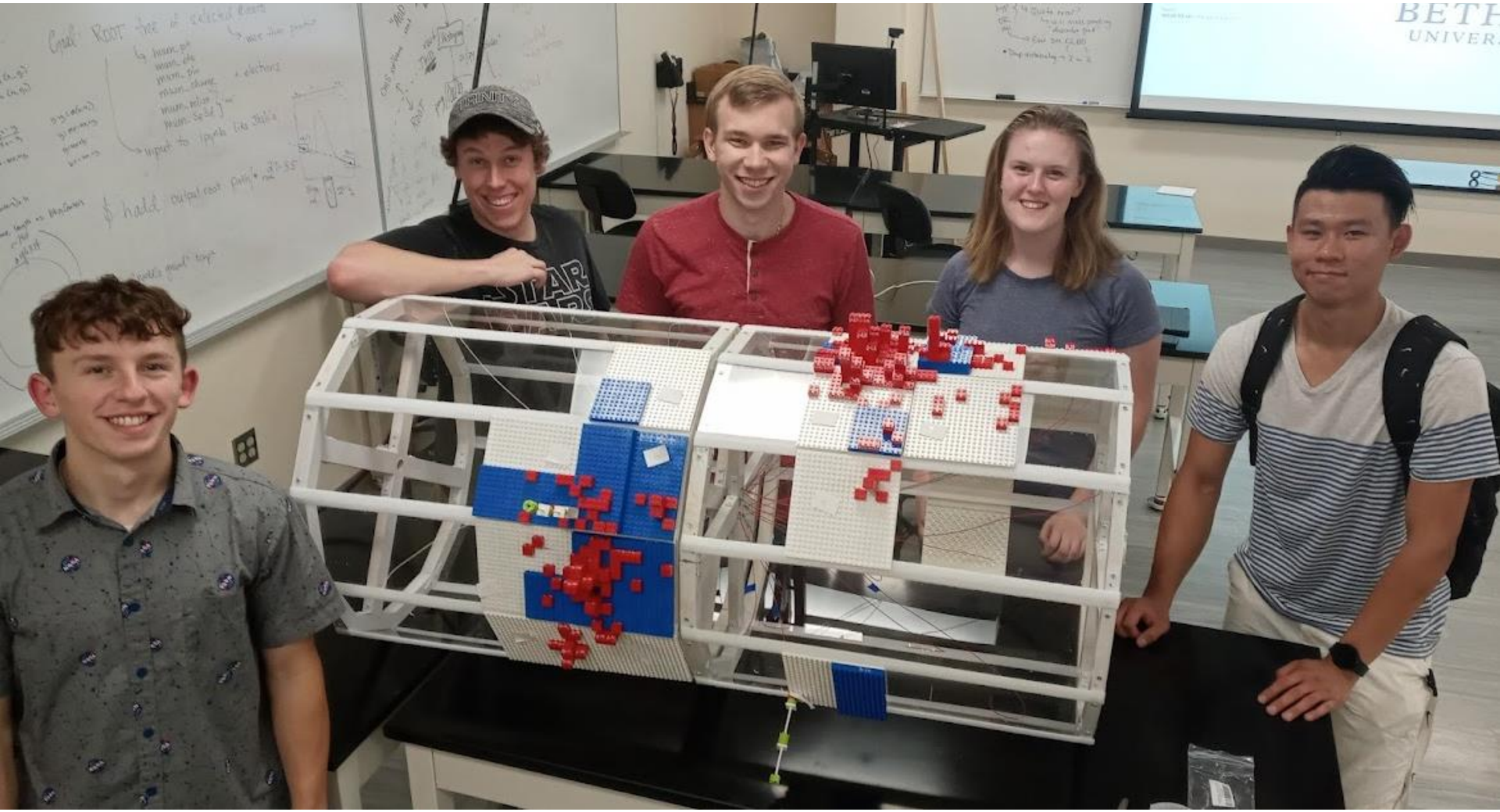


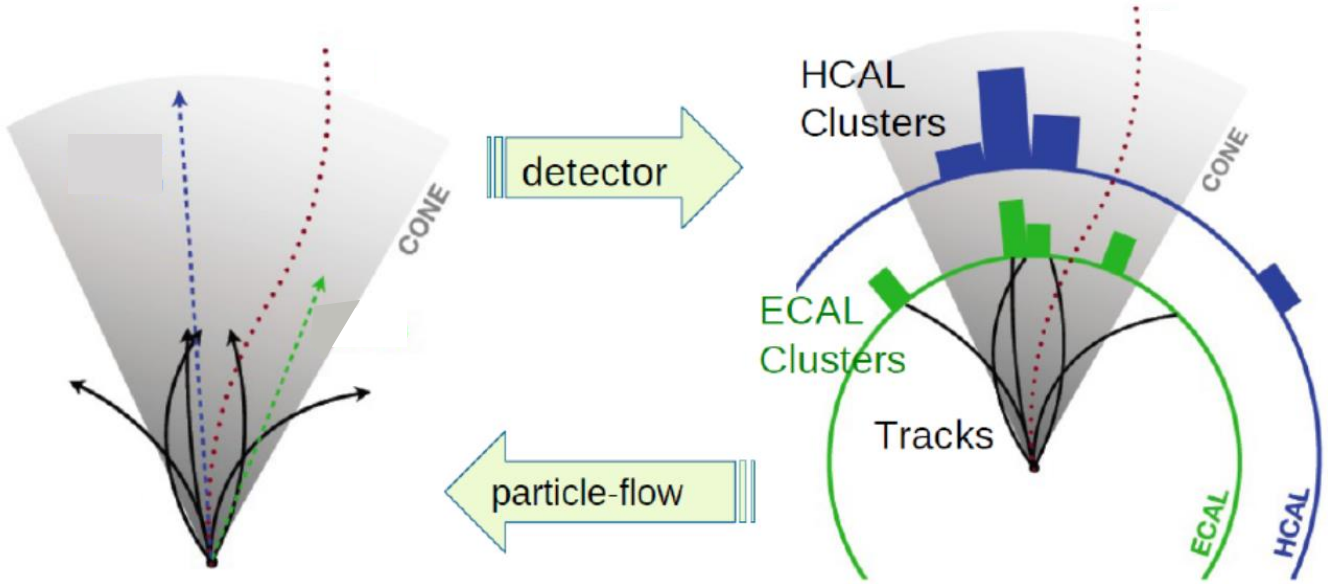
What do you know?

The goal of particle flow is to interpret detector hits as particles using:

A) only tracker information

B) only calorimeter information

C) combinations of all subsystems



What do you know?

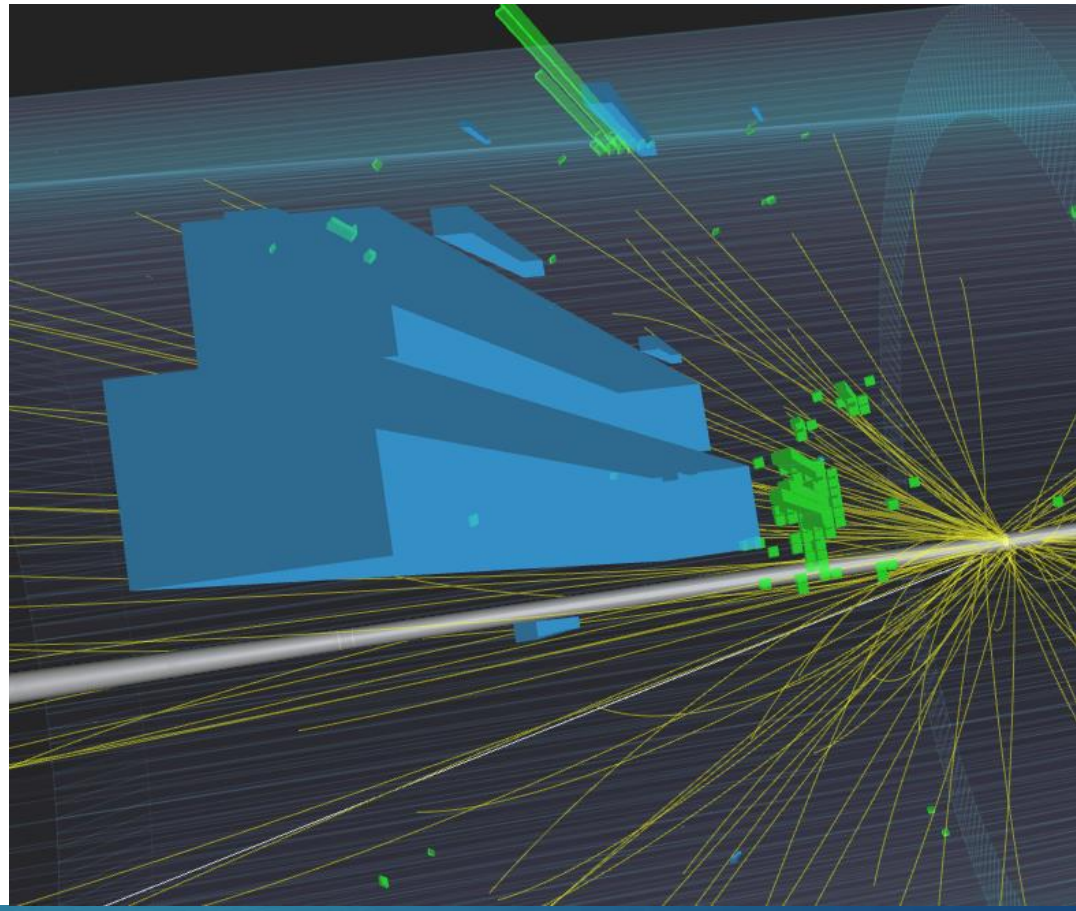
Which of the following is *not* a particle hypothesis used in particle flow?

A) electron

B) photon

C) neutron

D) muon

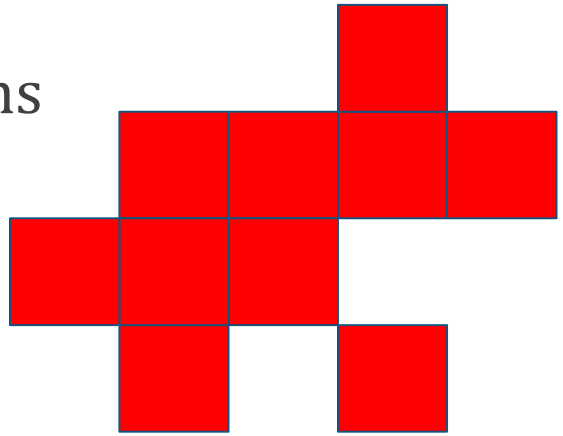


Clustering

First task: ECAL hits, HCAL hits → CLUSTERS

What is a cluster?

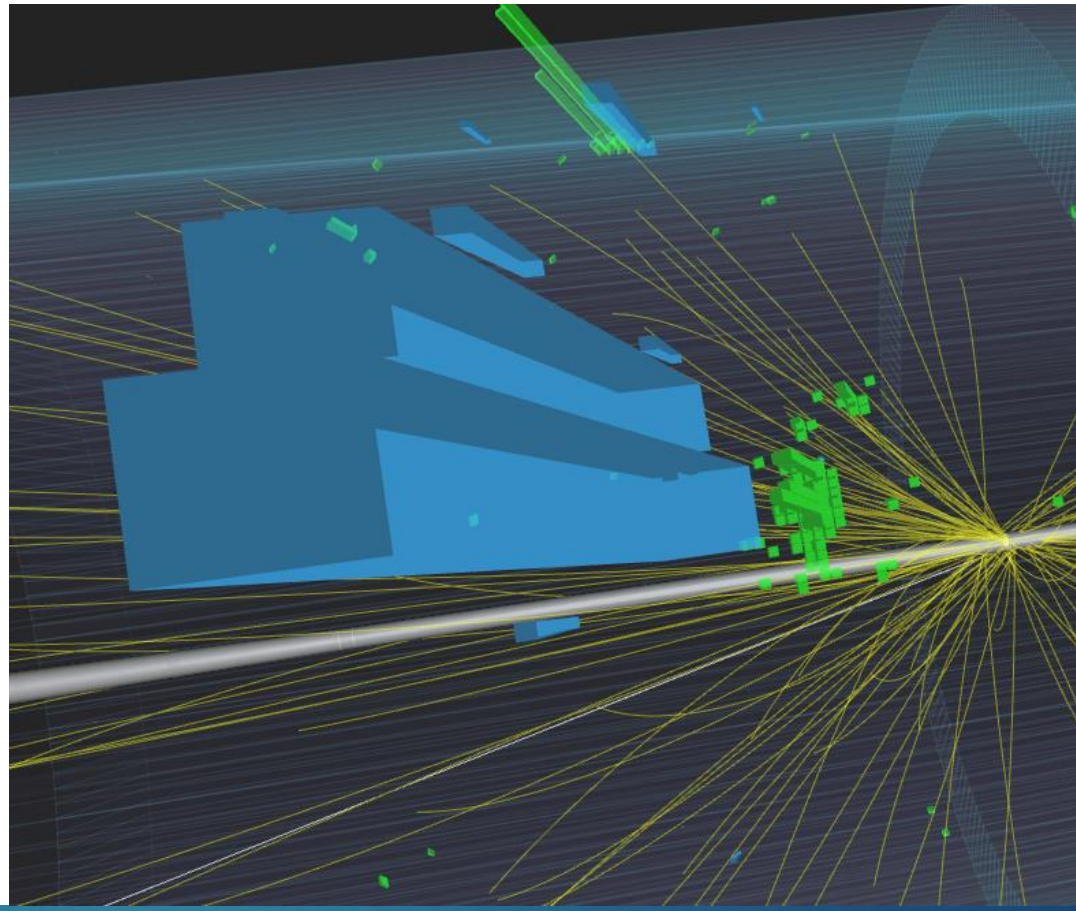
- "A cluster of energy in the calorimeter is a local group of calorimeter elements that are spatially consistent with a shower"
- Clustering = Making logical connections between calorimeter elements in order to make further hypotheses about the origin of the energy deposition
- Particle Flow defines clustering algorithms for ECAL and HCAL energy deposits



Clustering

First task: ECAL hits, HCAL hits → CLUSTERS

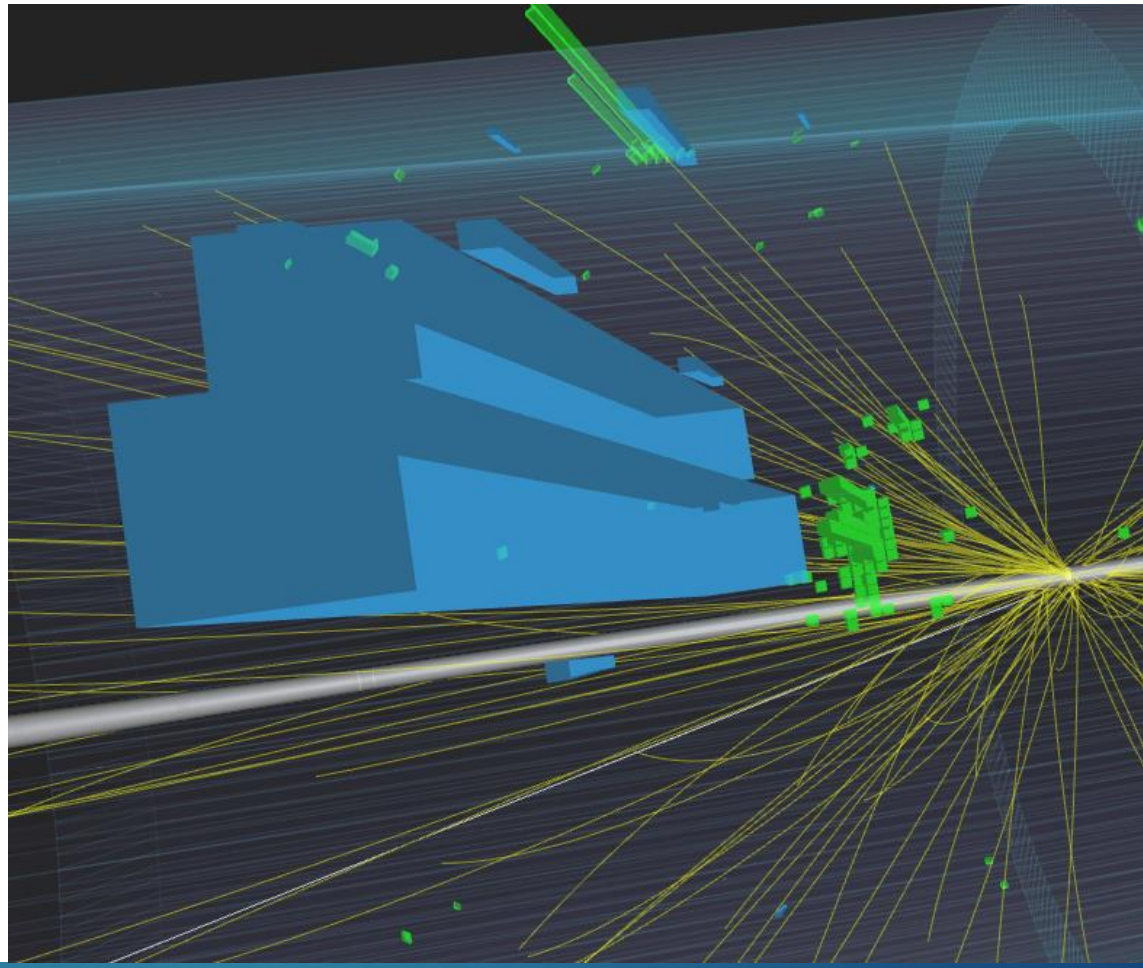
- Step 0: identify **topological clusters**
- Topological clusters need at least one "seed" with energy above a threshold
- Other elements must have energy above a "gathering" threshold



Clustering

First task: ECAL hits, HCAL hits → CLUSTERS

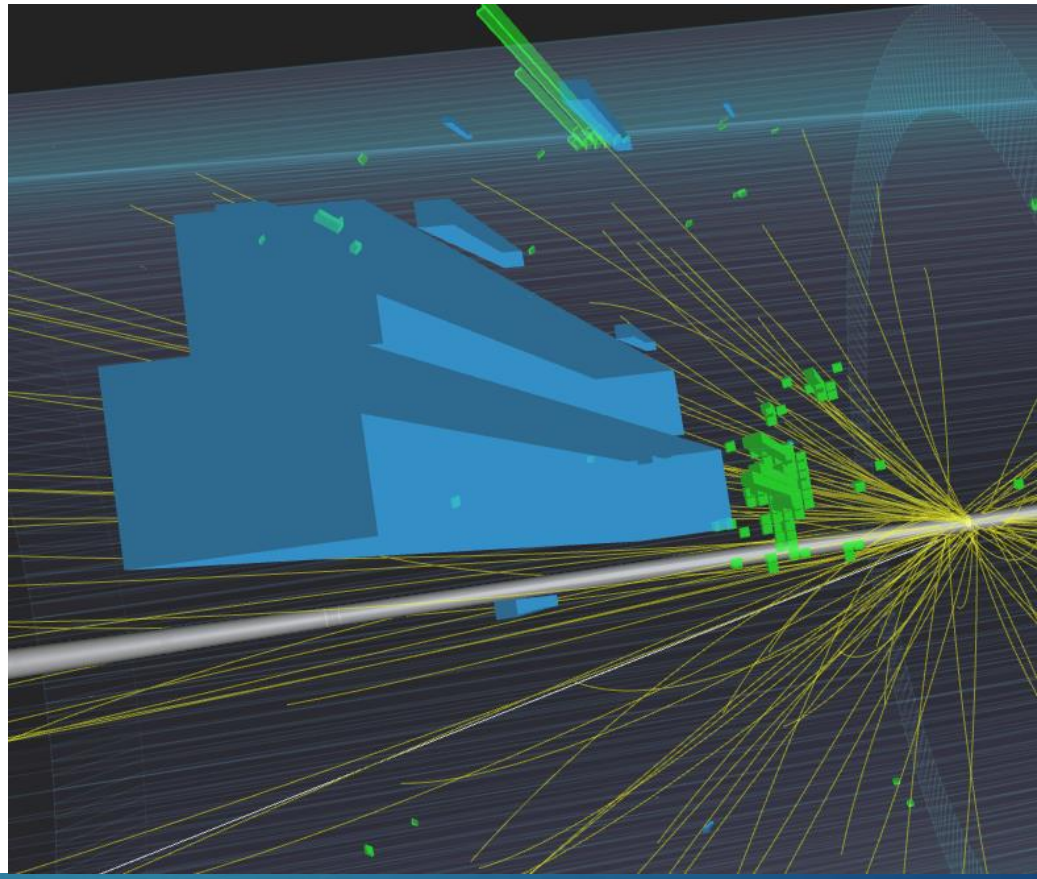
- Step 1: identify **seeds**
- How? Each local maximum in a topological cluster is a seed



Clustering

First task: ECAL hits, HCAL hits → CLUSTERS

- Step 2: compute **cluster properties: energy + direction**
- Single seed clusters:
  - Energy = sum of energy in all cluster cells
  - Center position = energy-weighted average of all cell positions



Clustering

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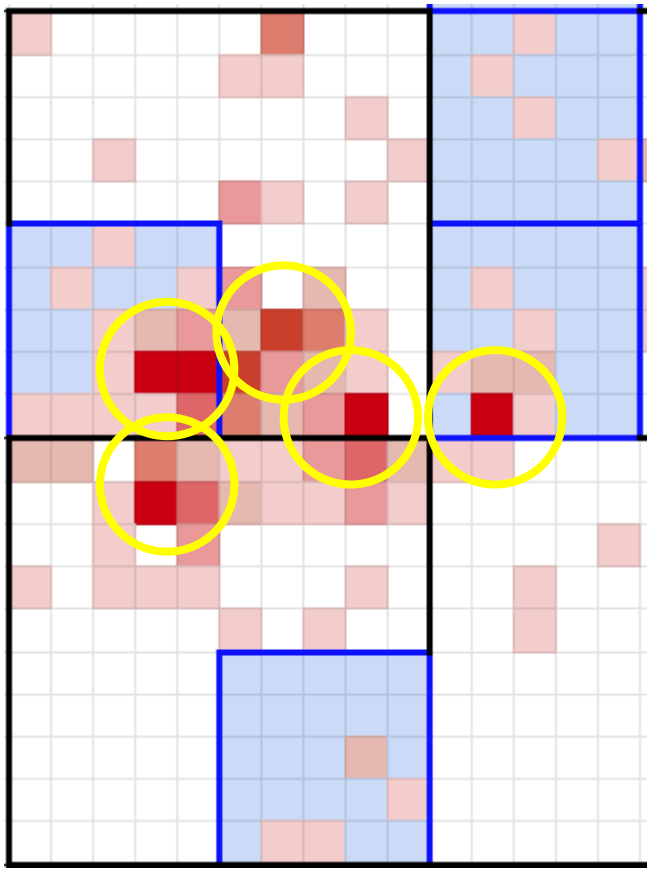
First task: ECAL hits, HCAL hits → CLUSTERS

- Step 2: compute **cluster properties: energy + direction**
- Multiple seed topoclusters:
  - Model each cluster as a 2D Gaussian
  - Energy in some cells is **shared** various clusters
    - **Rule**: the seed never shares its energy
  - It's an iterative process!
    - **Start: cluster = seed**
    - Calculate energy sharing for each hit
    - Recompute cluster energy
    - Recompute cluster position



Quiz!

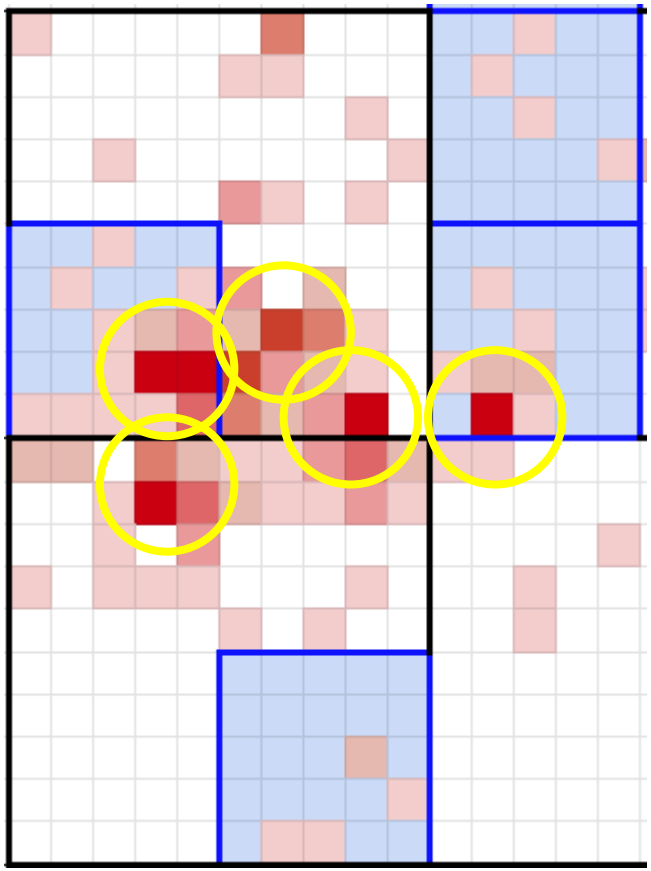
A single topological cluster is formed within the ECAL, which contains at least five cluster seeds. Which of the following is/are true?

A) The topological cluster must get broken into less than five clusters.

B) All of the seeds will share in the energy from all the other crystals in the topological cluster.

C) Each seed will share energy with the non-seed crystals according to physical proximity.

D) None of these are true.



Linking

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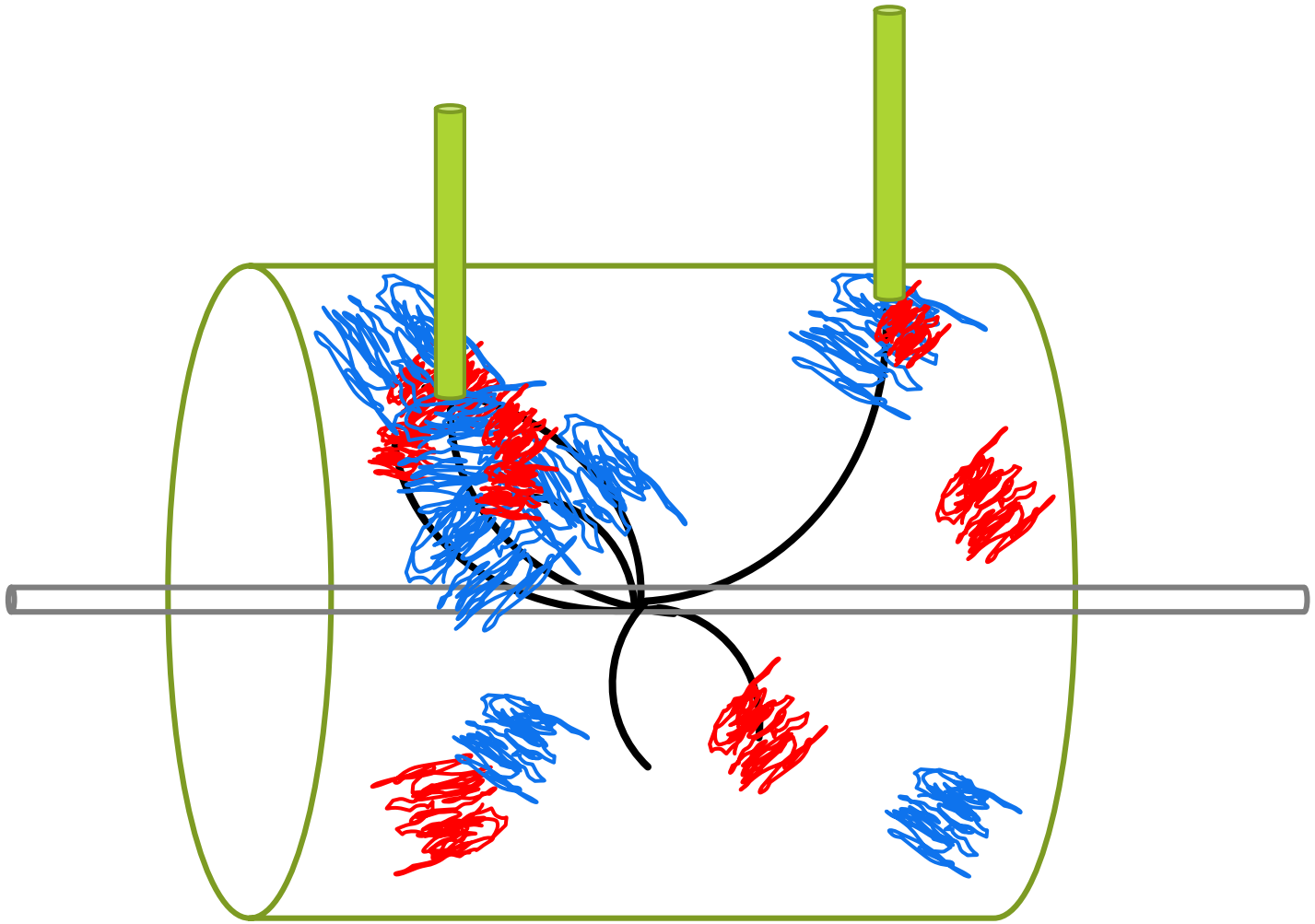
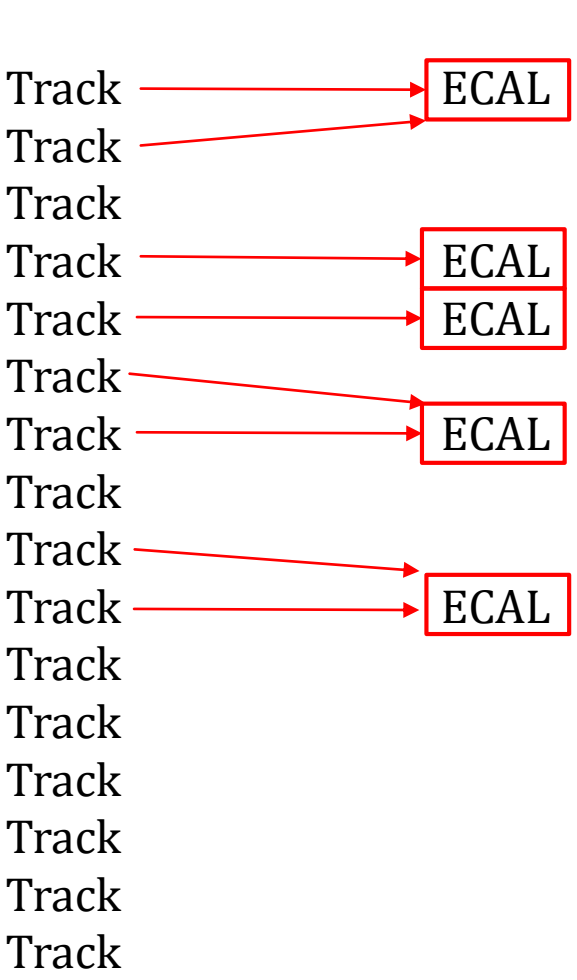
You now have: tracks, ECAL clusters, HCAL clusters, muon tracks



Linking

Connect them up!

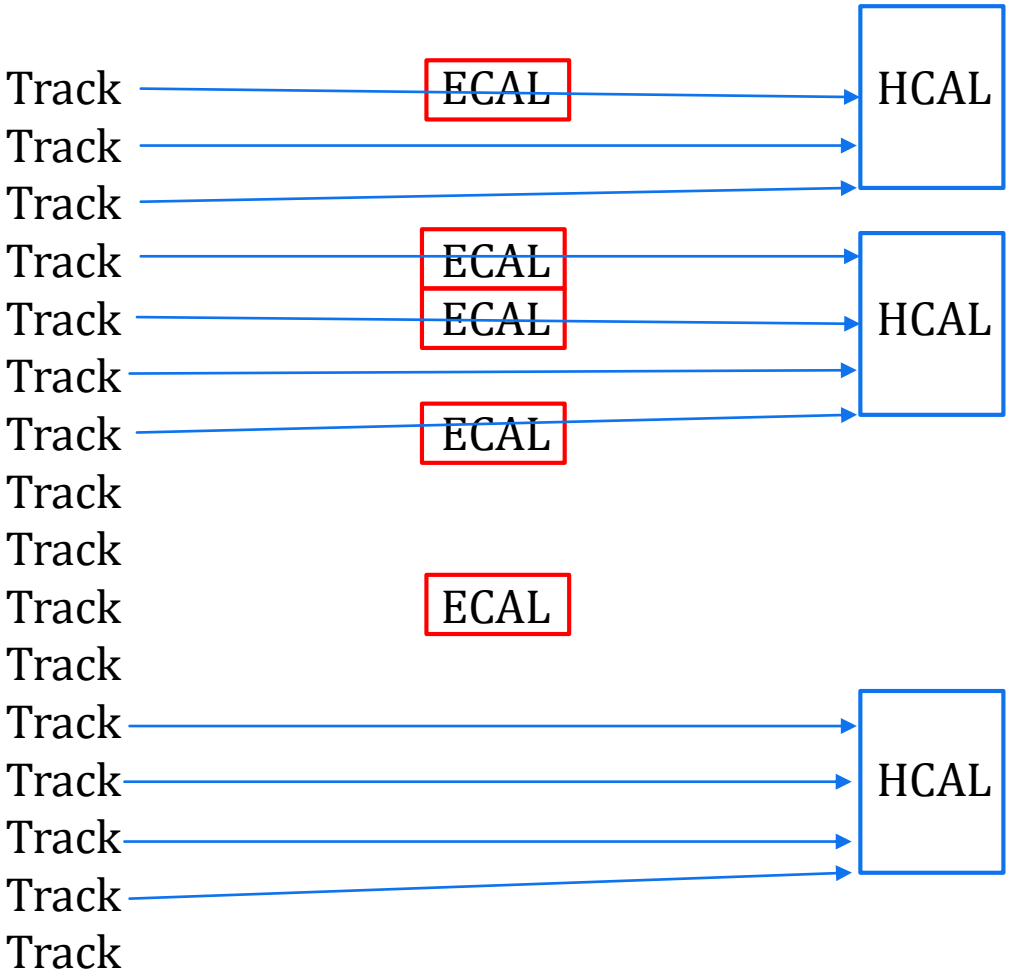


Rules:

- Small thing → 1 bigger thing
  - Closest big thing wins
- Must be "touching" in η-ϕ!
  - +1 block tolerance
  - Use track ECAL hit point

Linking

Connect them up!



Rules:

- Small thing → 1 bigger thing
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Linking

Connect them up!

Track
Track
Track
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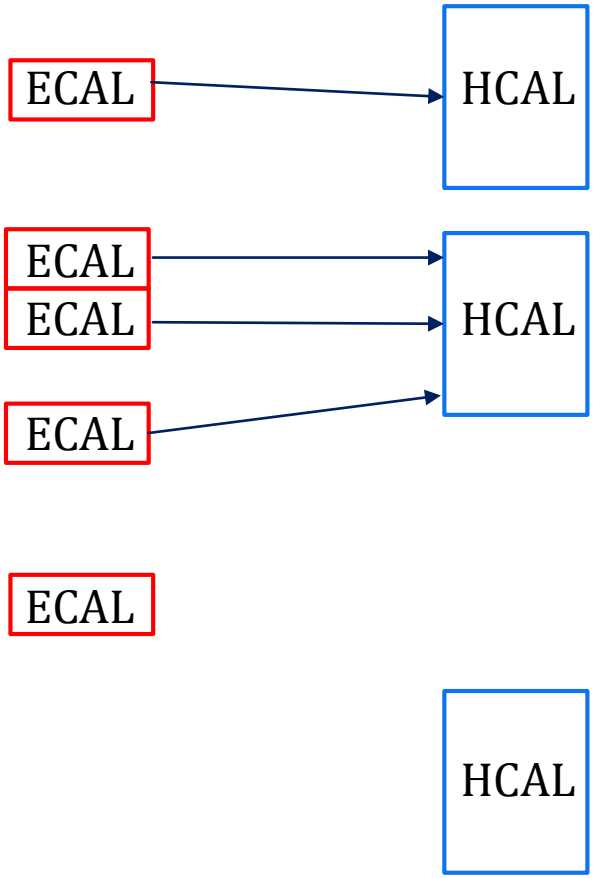


Muon

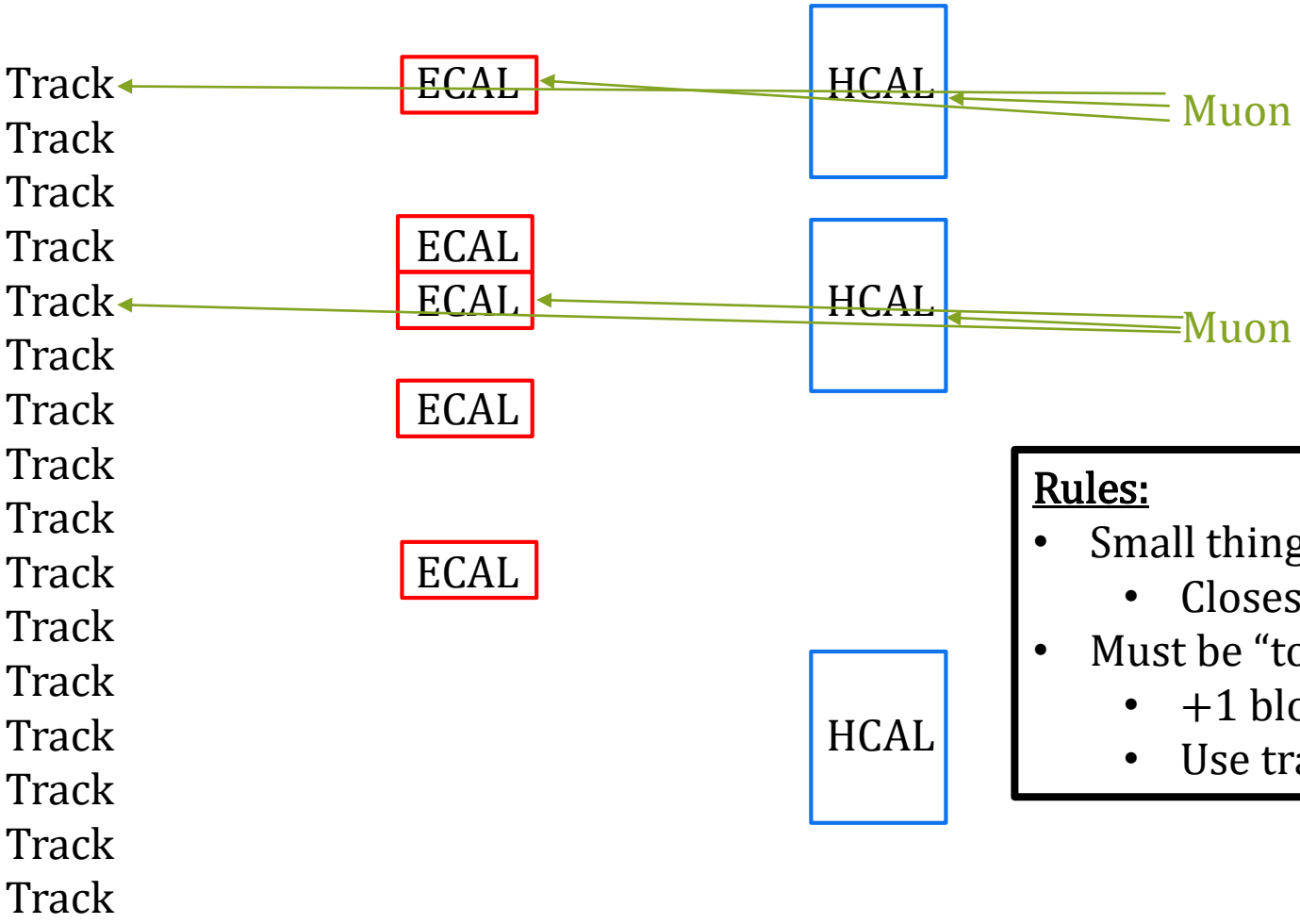
Muon

Rules:

- Small thing → 1 bigger thing
  - Closest big thing wins
- Must be "touching" in η-ϕ!
  - +1 block tolerance
  - Use track ECAL hit point

Linking

Connect them up!



Rules:

- Small thing → 1 bigger thing
  - Closest big thing wins
- Must be "touching" in η-ϕ!
  - +1 block tolerance
  - Use track ECAL hit point

Quiz!

Two tracks have trajectories that meet a single ECAL cluster that has an energy of 5 GeV. One track has a momentum of 4 GeV and meets the ECAL surface near the edge of the ECAL cluster area. The second track has a momentum of 2 GeV and meets the ECAL surface near the center of the ECAL cluster. Which links will the particle flow algorithm make?

A) Only the track closest to the center of the ECAL cluster will be linked to the cluster.

B) Both tracks will be linked to the ECAL cluster.

C) Only the highest momentum track will be linked to the ECAL cluster.

D) Since both tracks have lower energy than the ECAL cluster, none of them will be linked.

Quiz!

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Three separate clusters in the ECAL are associated with one HCAL cluster (the seed for each cluster is in front of the HCAL cluster). Each ECAL cluster has over 5 GeV of energy, and the HCAL cluster has 2 GeV of energy. When particle flow attempts to link objects together, how many items are linked together?

A) Only the closest ECAL cluster to the center of the tower will be linked to the HCAL, since proximity is most important.

B) All three ECAL clusters will be linked with the HCAL.

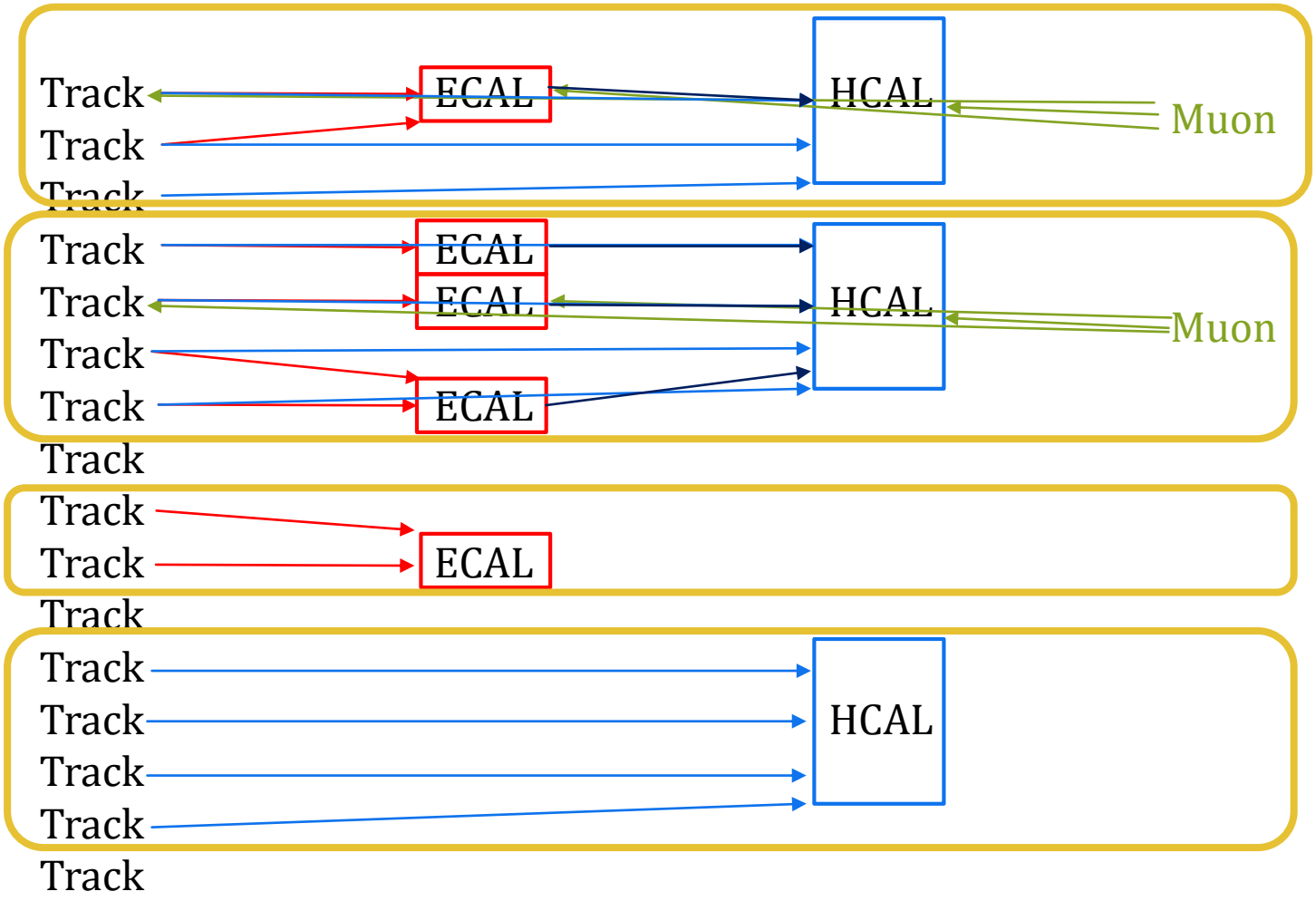
C) The highest energy ECAL cluster will be linked with the HCAL, since the HCAL is likely leakage energy from that particle.

D) Since the clusters all have more energy than the HCAL cluster, none will be linked.

E) The lowest energy ECAL cluster will be linked with the HCAL, since that would be likely to be the closest energy match.

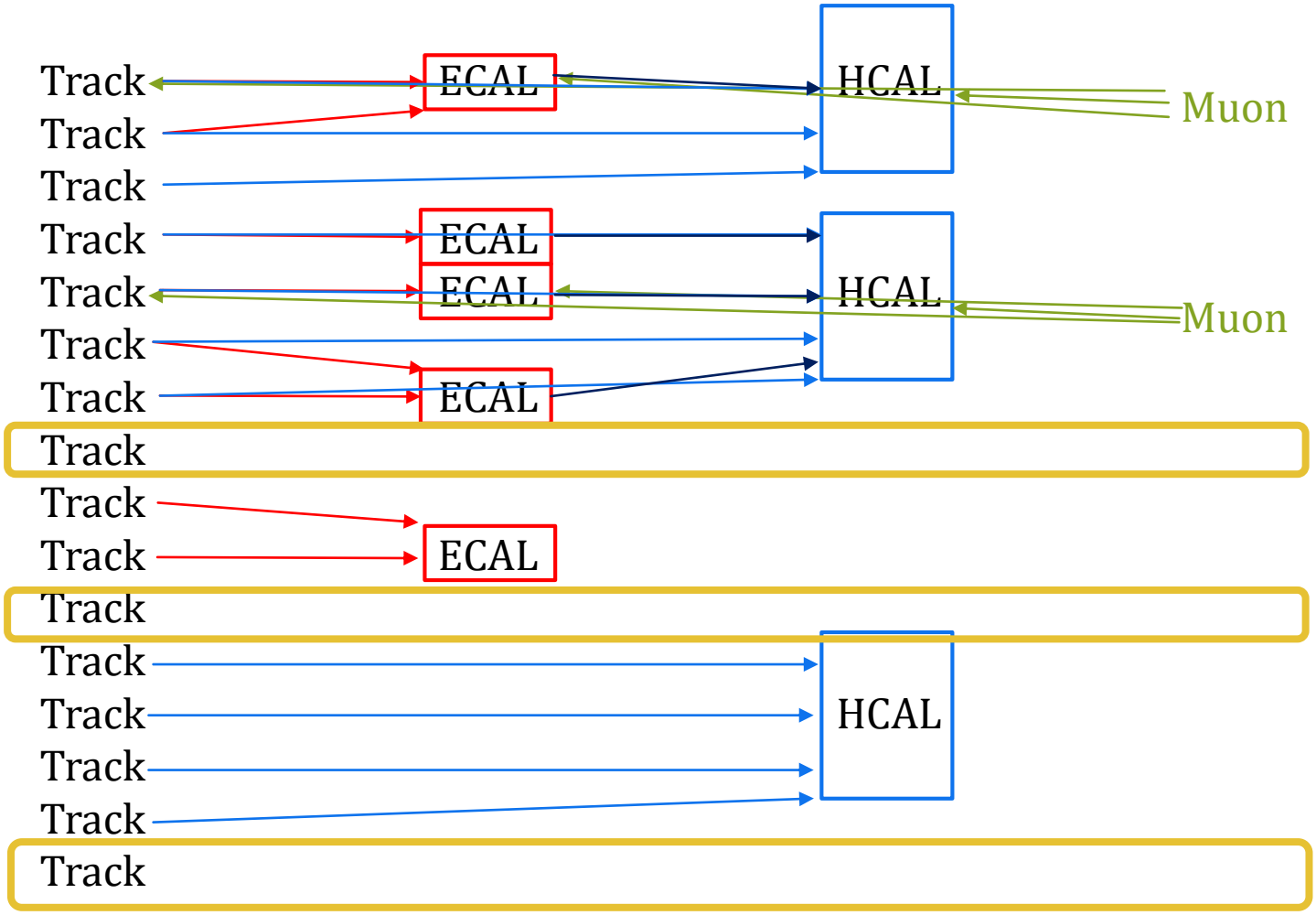
Blocking

Blocks consist of all linked objects

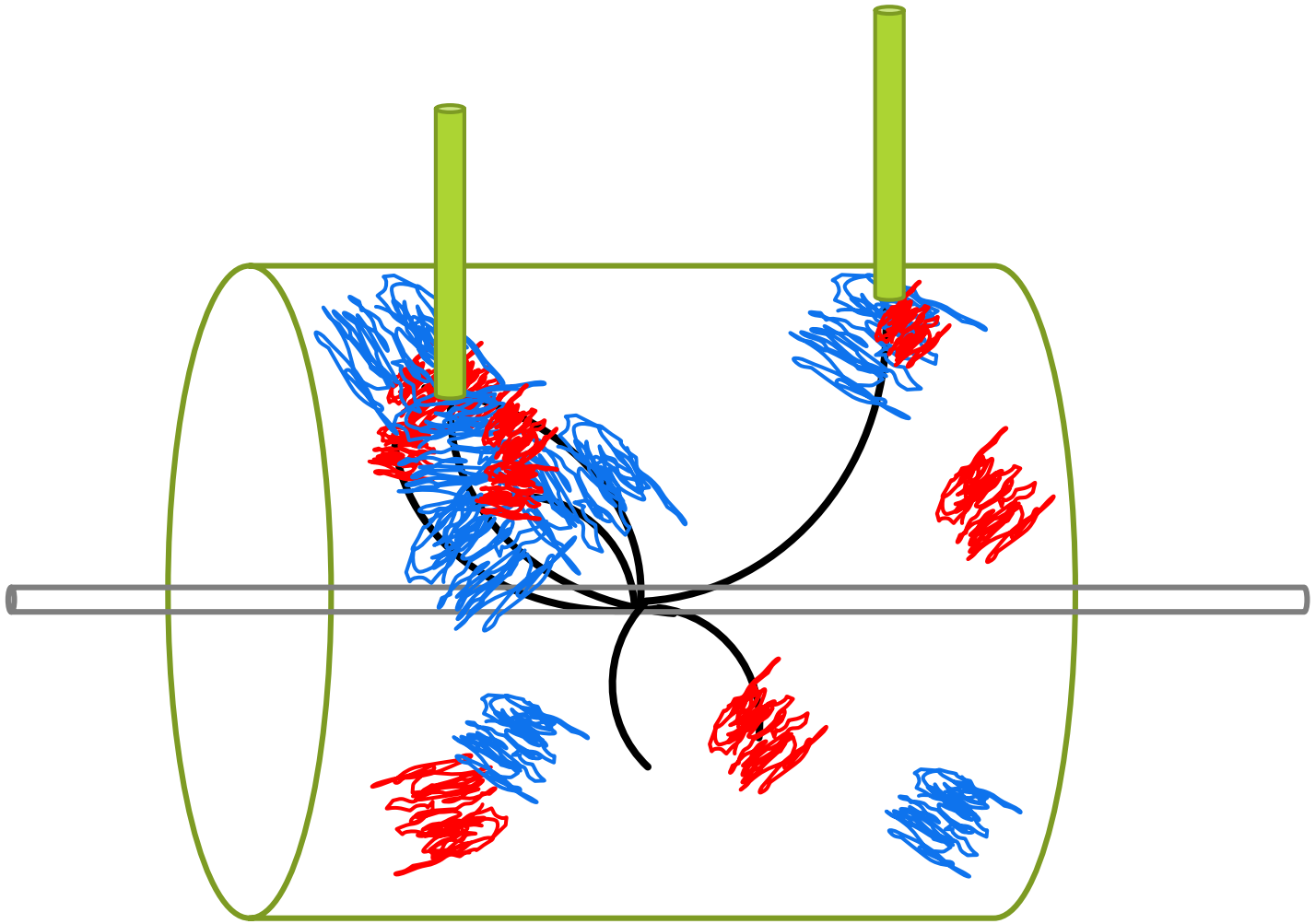


Blocking

Blocks consist of all linked objects

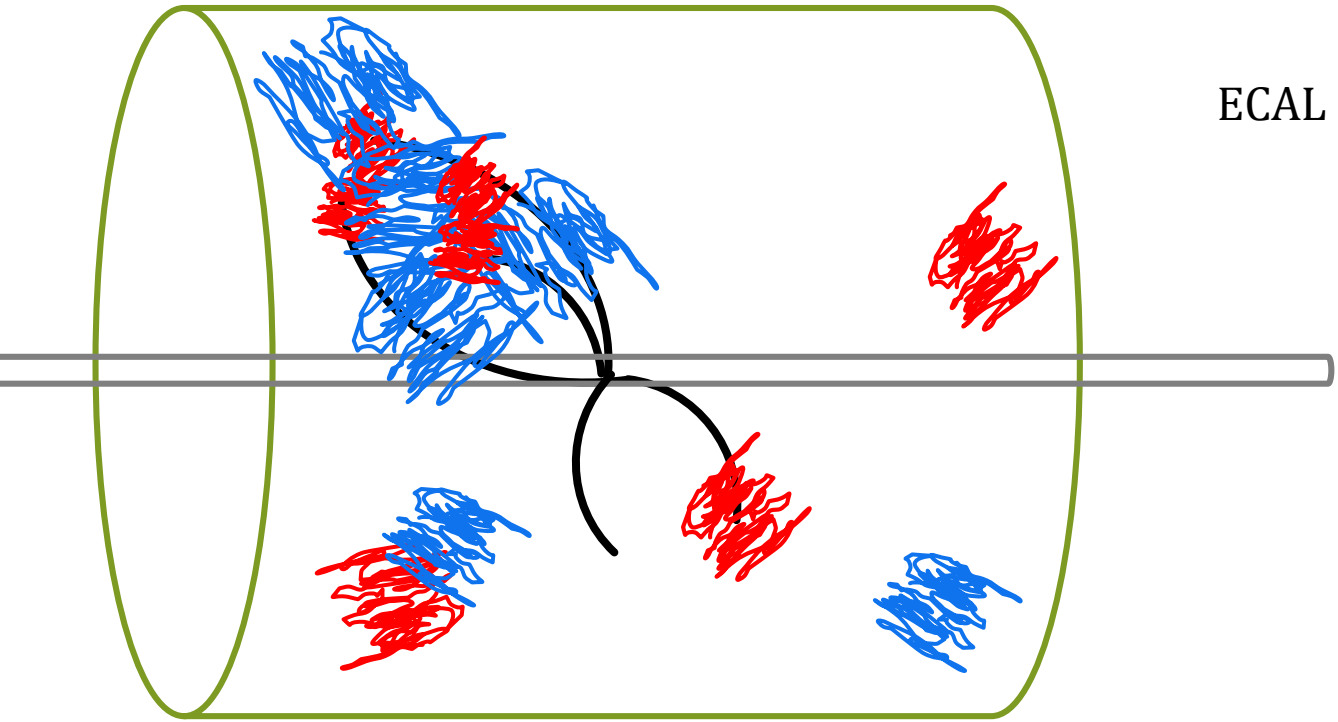


Standalone muon track + inner track = **GLOBAL MUON**



Electrons and photons

Electron = electron + brem photons + pair productions



Isolated photon:

ECAL cluster with $E_T > 10$ GeV
no track link

Isolated electron:

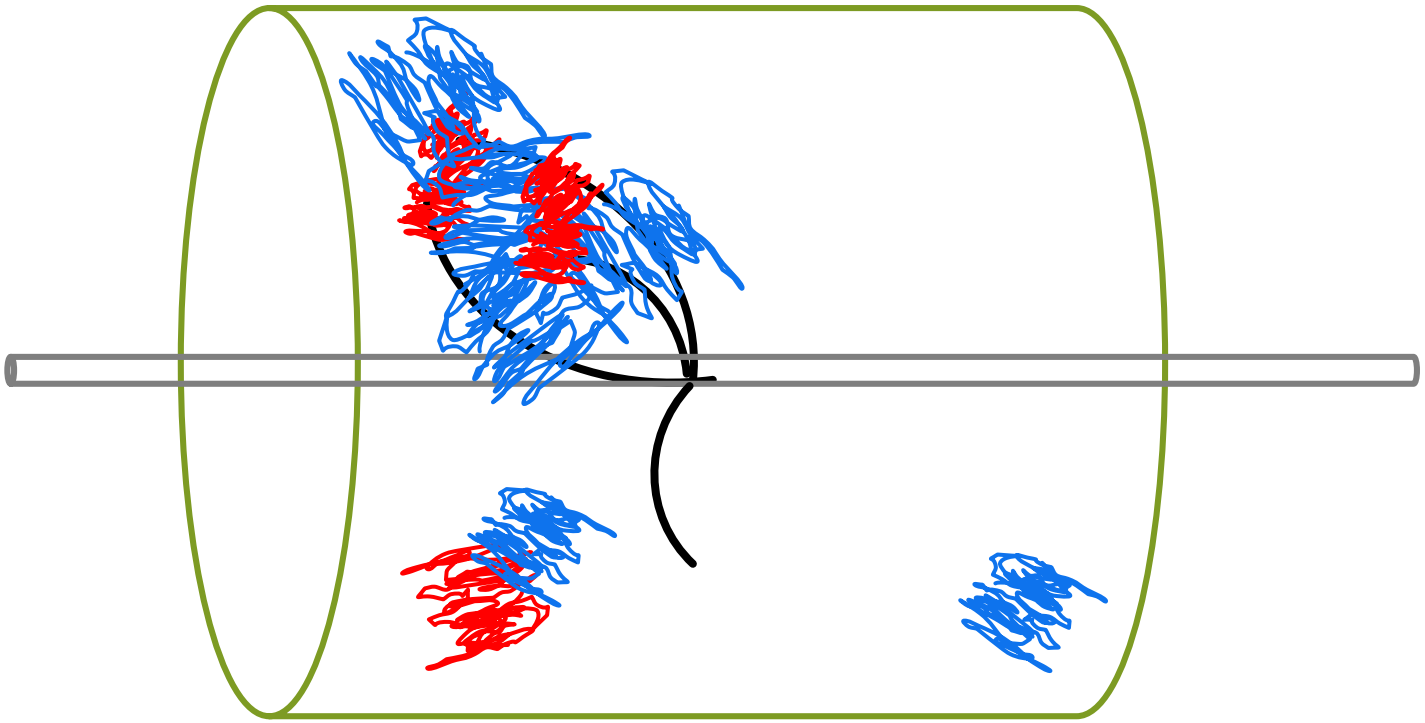
2 GeV track linked to
ECAL cluster with < 3
additional track links
E/p ~ 1!

Neural hadrons and photons

All other clusters without track links

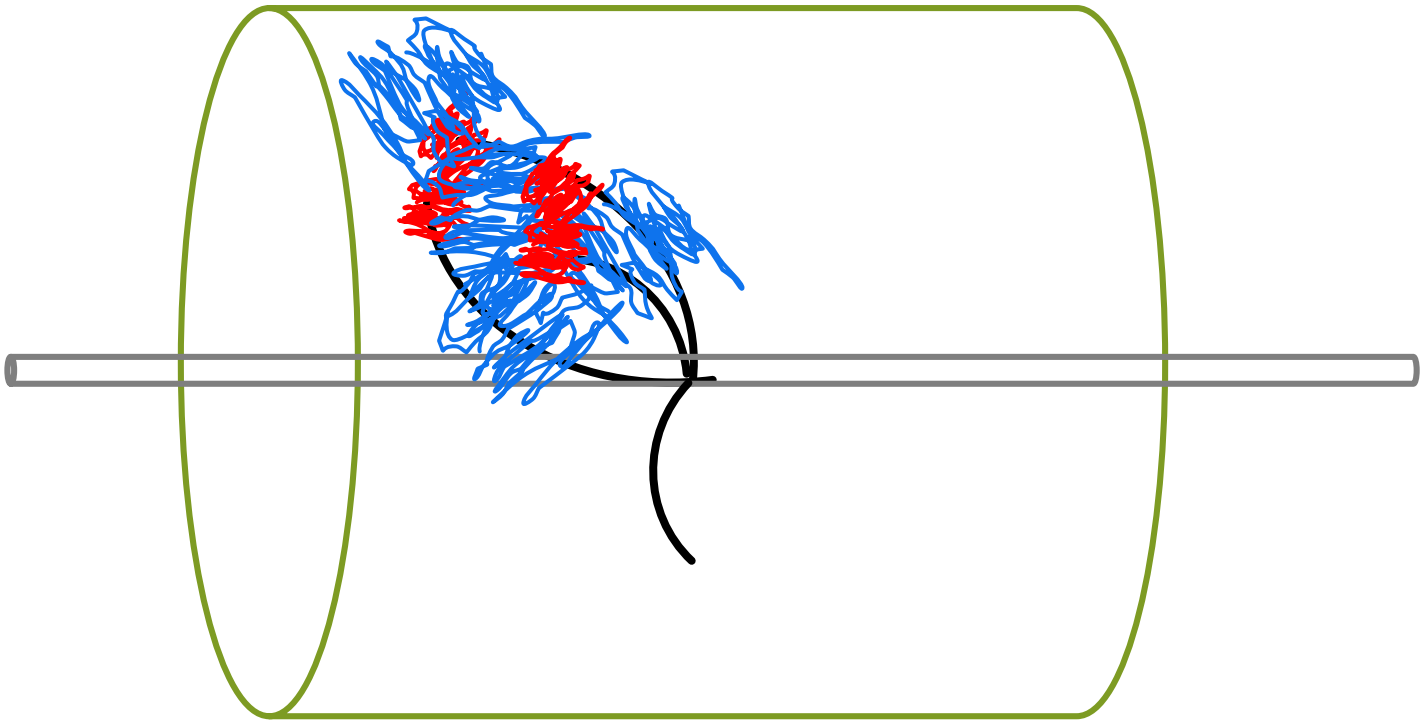
Non-iso photon: ECAL clusters without track links

Neural hadron: HCAL clusters without track links



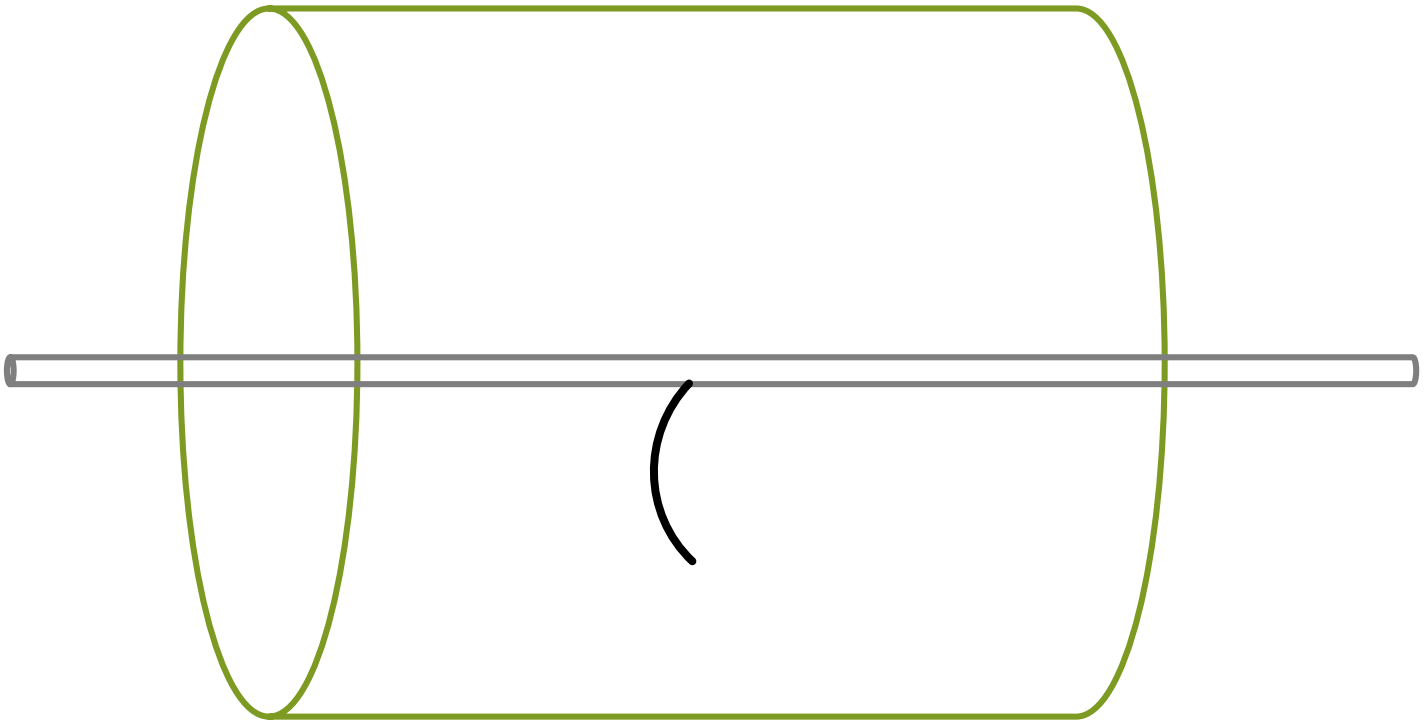
Charged hadrons

All other clusters have track links & are **charged hadrons!**



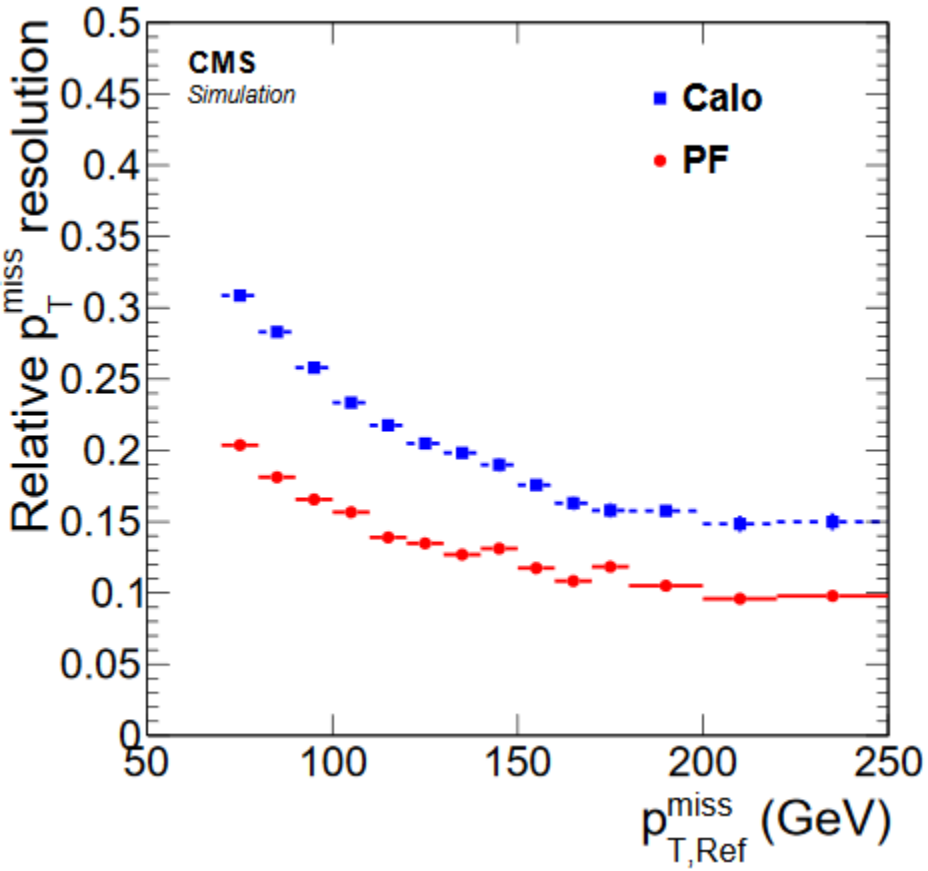
Charged hadrons

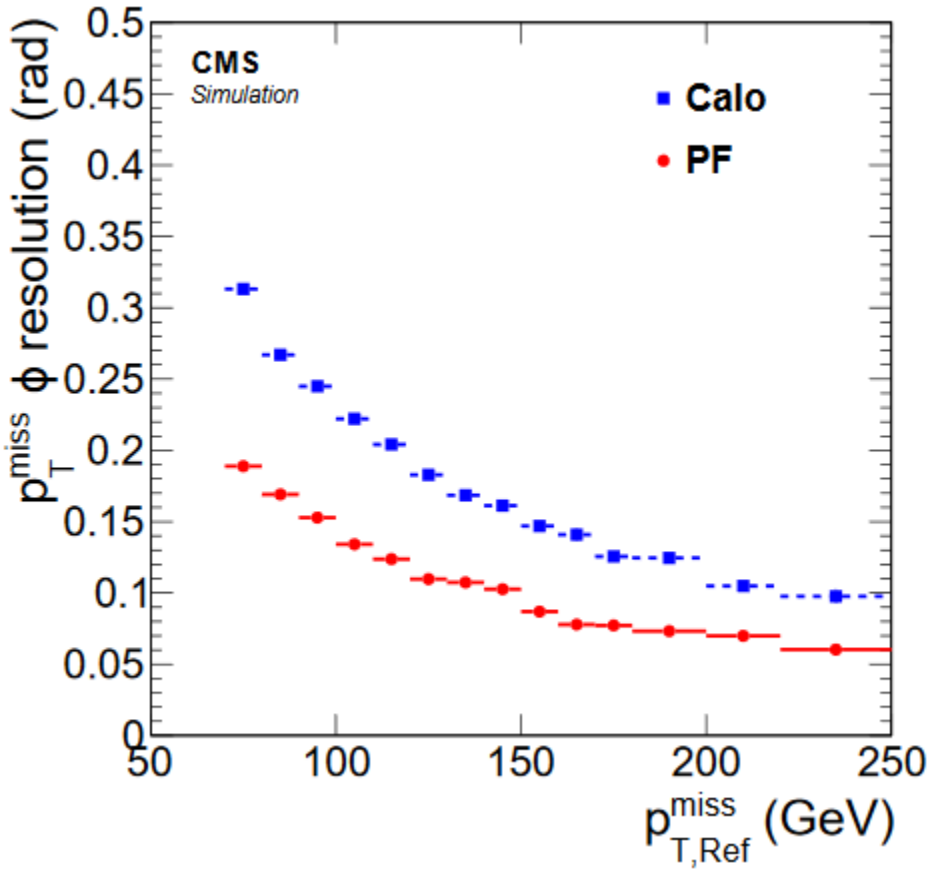
Finally, loner tracks become **charged hadrons** too



Post-processing

- **Raw MET**: $\boldsymbol{p}_{\mathrm{T}}^{\mathbf{miss}} = -\sum_{i=1}^{N\ \mathbf{particles}} \boldsymbol{p}_{\mathrm{T},i}$
- Sometimes wrong particle hypothesis inflate MET. Particle flow does many checks, especially with muons, to make sure



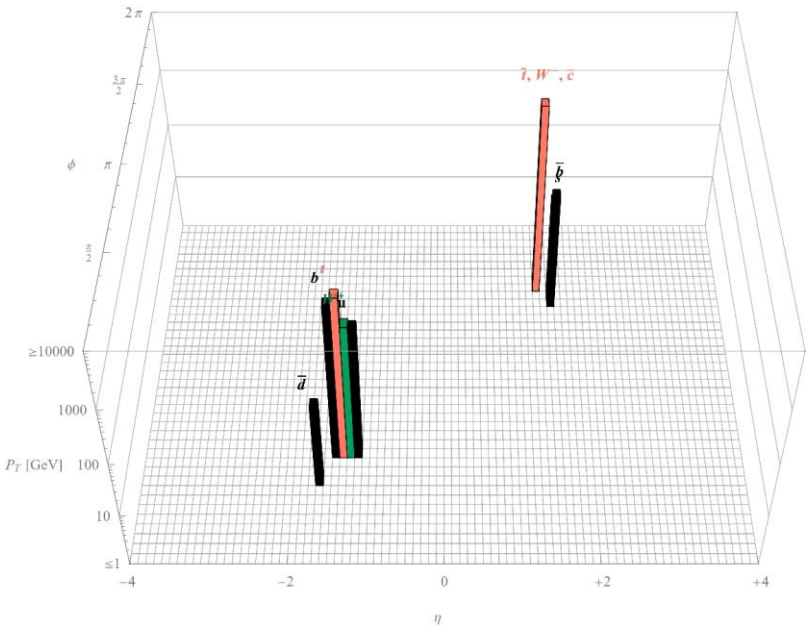


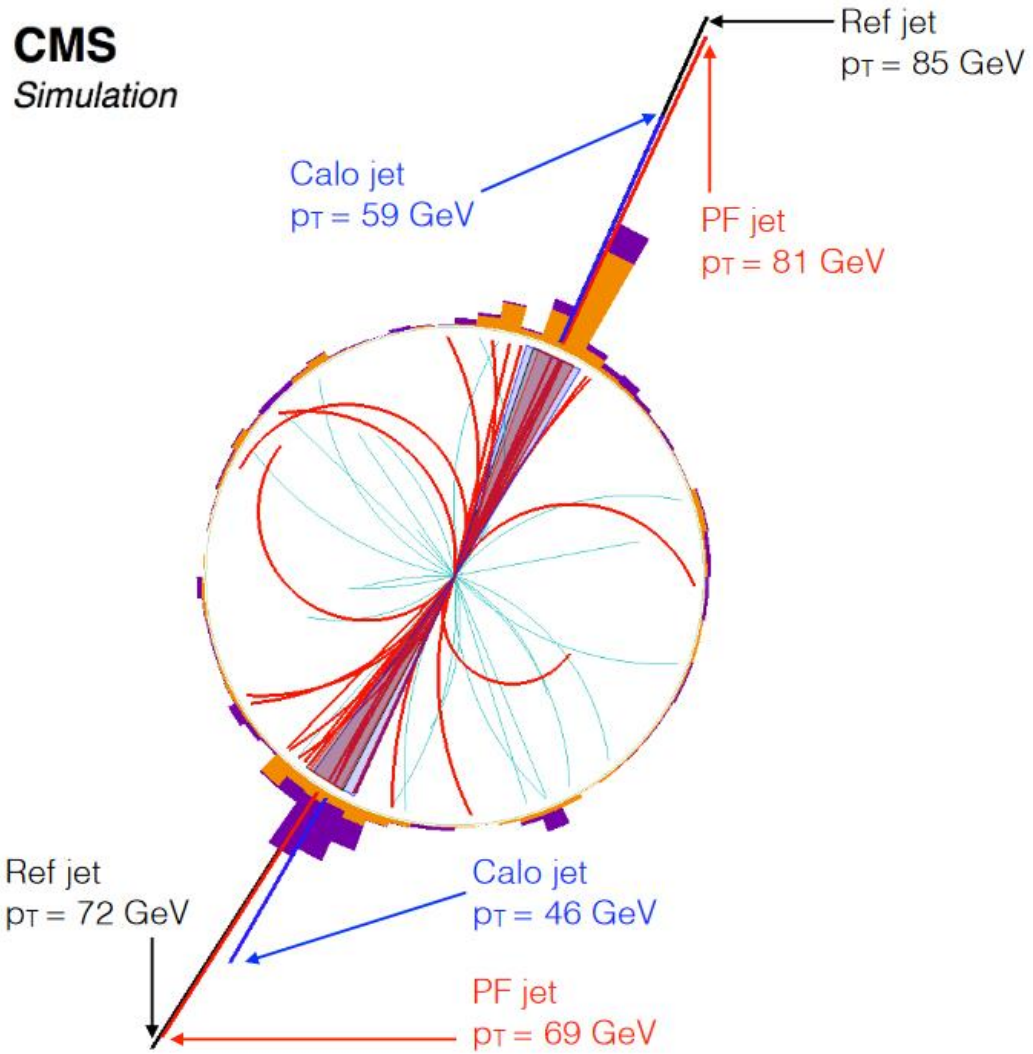
Post - PF

- Jet clustering with anti-kT

$$d_{ij} = \min\left(p_{\mathrm{T},i}^{-2}, p_{\mathrm{T},j}^{-2}\right)\frac{\Delta\theta_{ij}^2}{R^2}$$

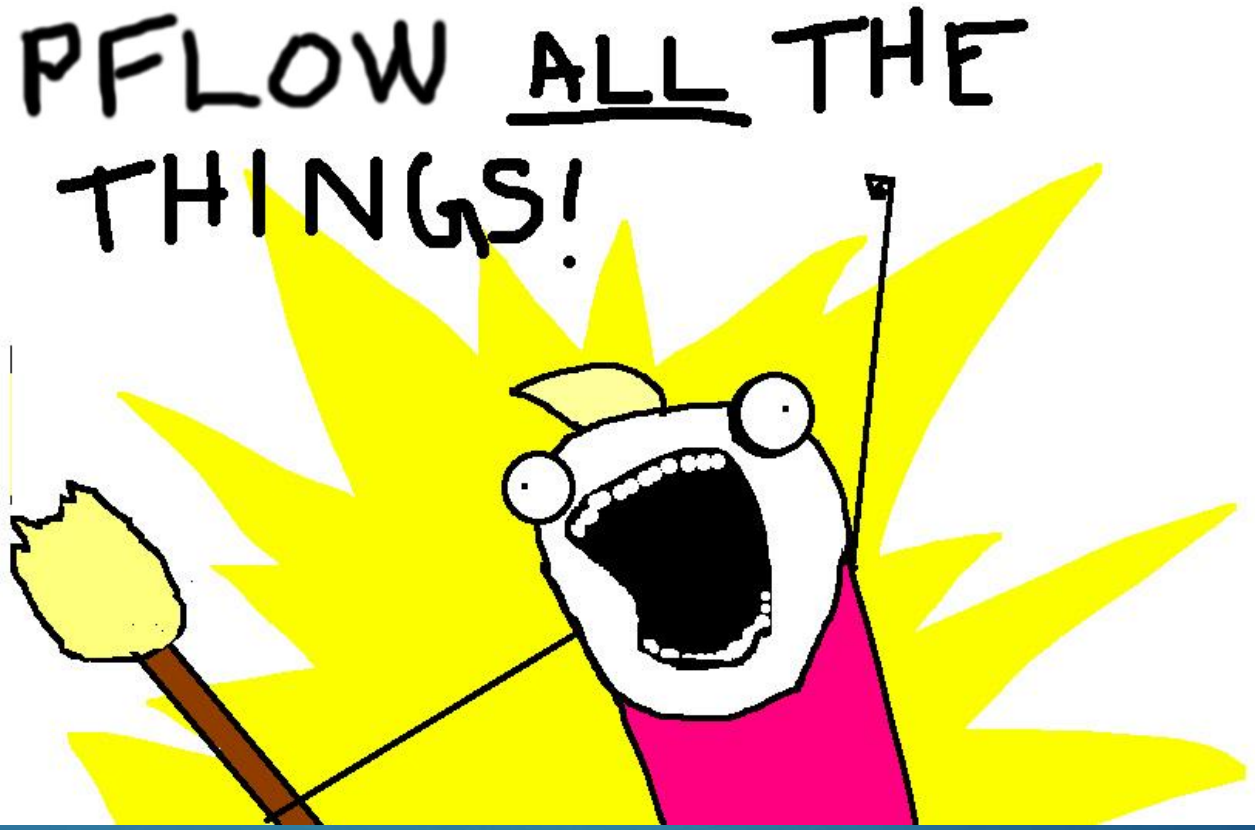
Until $d_{ij} \simeq p_{\mathrm{T},i}^{-2}$





Other uses of PF

- Lepton isolation
- Hadronic tau reconstruction
- HLT paths with jets, MET, taus, isolated leptons
- Pileup mitigation



Opening fireworks

- http://fireworks.cern.ch/
- /store/group/upgrade/visualization/dy.root

Group exercise: EW events

- Go to event #3 with the right arrow
- What different types of objects are there?
- How many muons are hidden from view?
- Choose 2 muons and find their invariant mass.

Higgs events: team exercise

- Open /store/group/upgrade/visualization/ggh4l.root

RED TEAM	BLUE TEAM	GREEN TEAM
Event 254045	Event 254054	Event 254110
How many leptons? What is the event? What is M(H)? What are the M(Z) values?	What is the event? Can you pair the muons into Z's? Are all the muons isolated?	What is the event? Can you pair the electrons into Z's? Are the electrons isolated?

Top events: team exercise

- Open /store/group/upgrade/visualization/ttjets.root
- t → W + b, so you can explore b-tagged jets by making a table view or adding a filtered jet collection
- A genParticles collection is available too to help

RED TEAM	BLUE TEAM	GREEN TEAM
Event 24518	Event 24590	Event 1876862
Can you find jets from W's and t's?	What is the source of all the muons?	Are the muons close to jets?

Data events: team exercise

- Open a data file in fireworks

RED TEAM

SingleElectron
1023:1523919869
48:72793234

What kind of event might this be? How could you justify your answer?

BLUE TEAM

SingleMuon
Both events

What kind of event might this be? How could you justify your answer?

GREEN TEAM

SingleElectron
48:71915470
1023:1523757530

What kind of event might this be? How could you justify your answer?

Bad events: team exercise

- Cosmics: muons from the atmosphere can reach CMS. Look for straight-line hits in the muon chambers
- Beam halo: protons from the LHC. Scattering can create muons traveling along the beam axis – hits with same phi.

RED TEAM	BLUE TEAM	GREEN TEAM
2016B1 2016C1	2016D1 2016B2	2016D2 2016D3
What is this?	What is this?	What is this?

ISpy

- Fireworks might not give you pretty enough or high enough resolution images for a publication
- ISpy is a web-based tool for visualizing events
- https://github.com/cms-outreach/ispy-analyzers