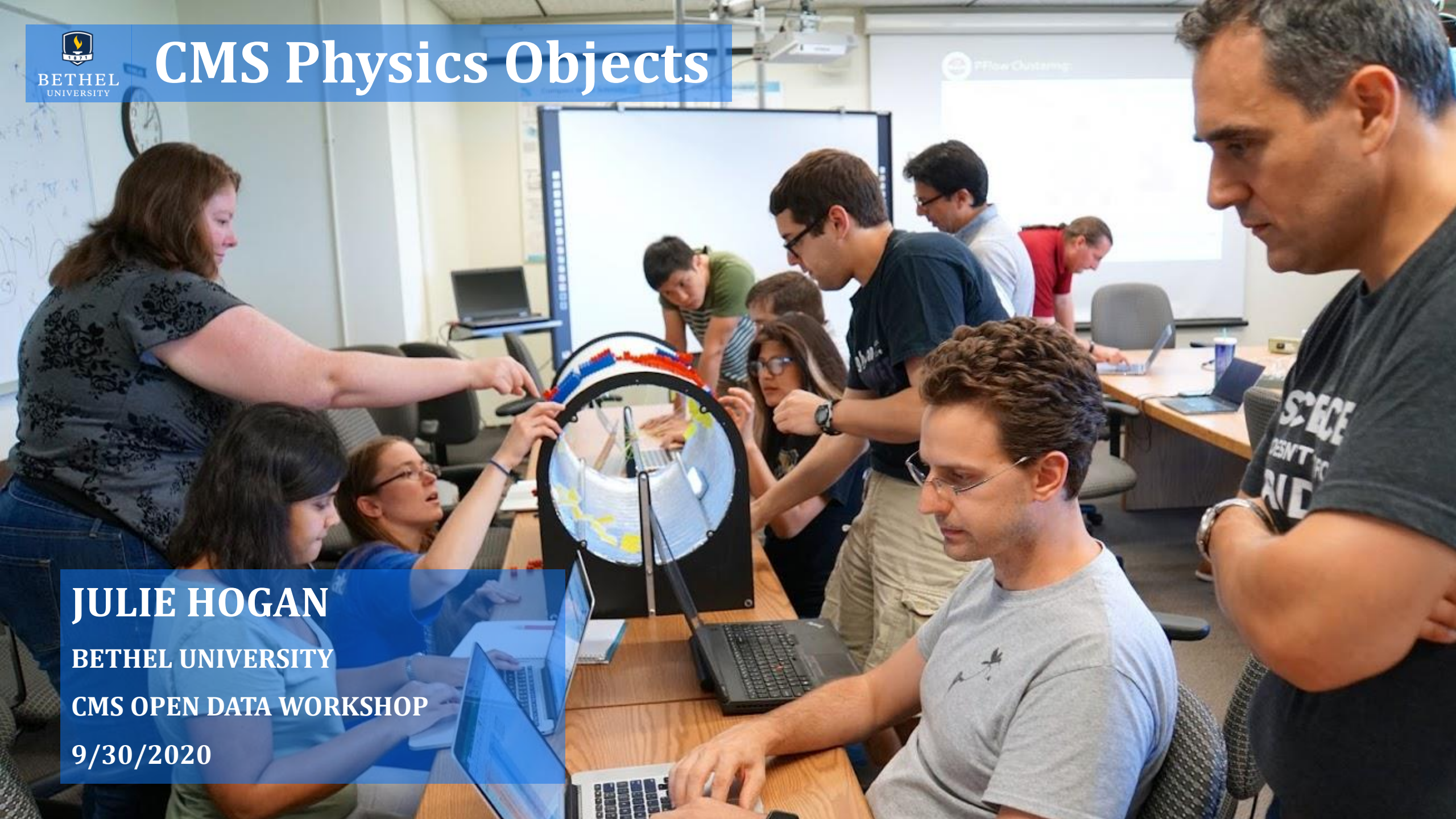
CMS Physics Objects



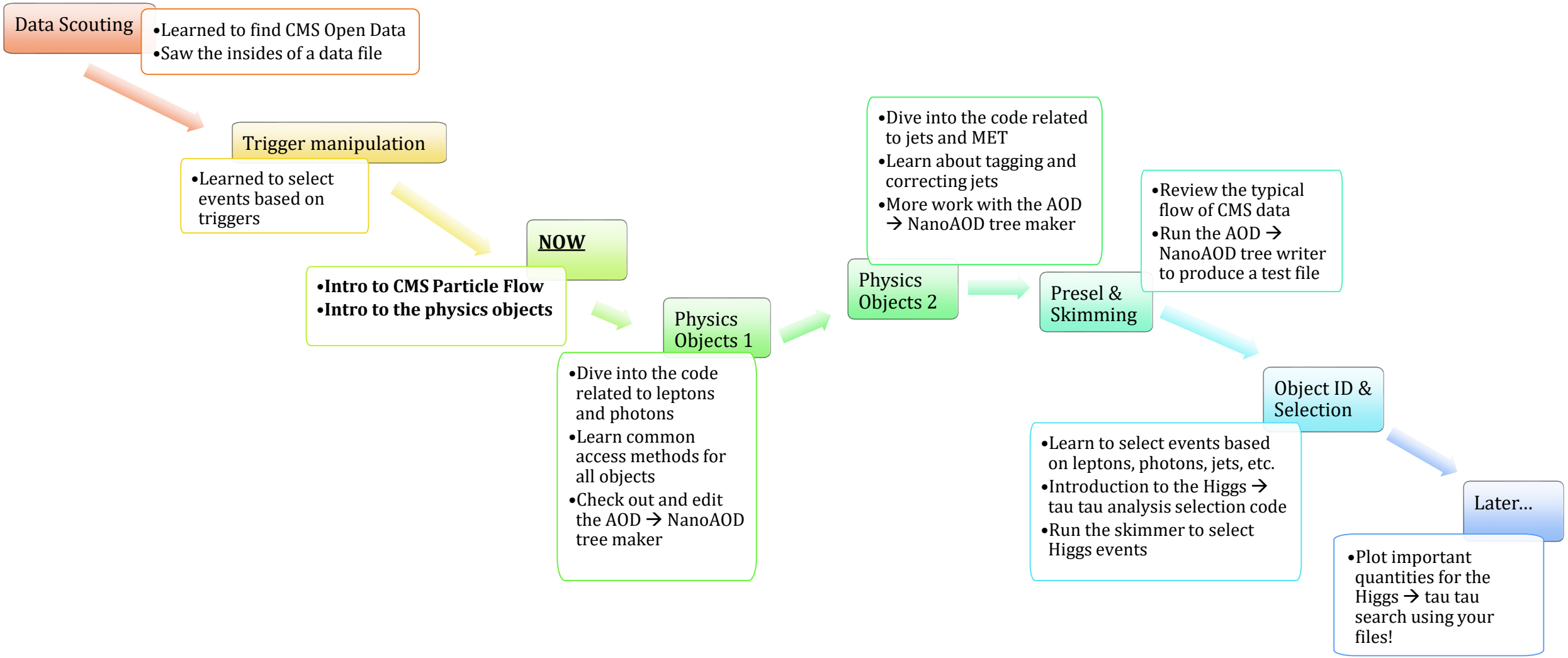
JULIE HOGAN

BETHEL UNIVERSITY

CMS OPEN DATA WORKSHOP

9/30/2020

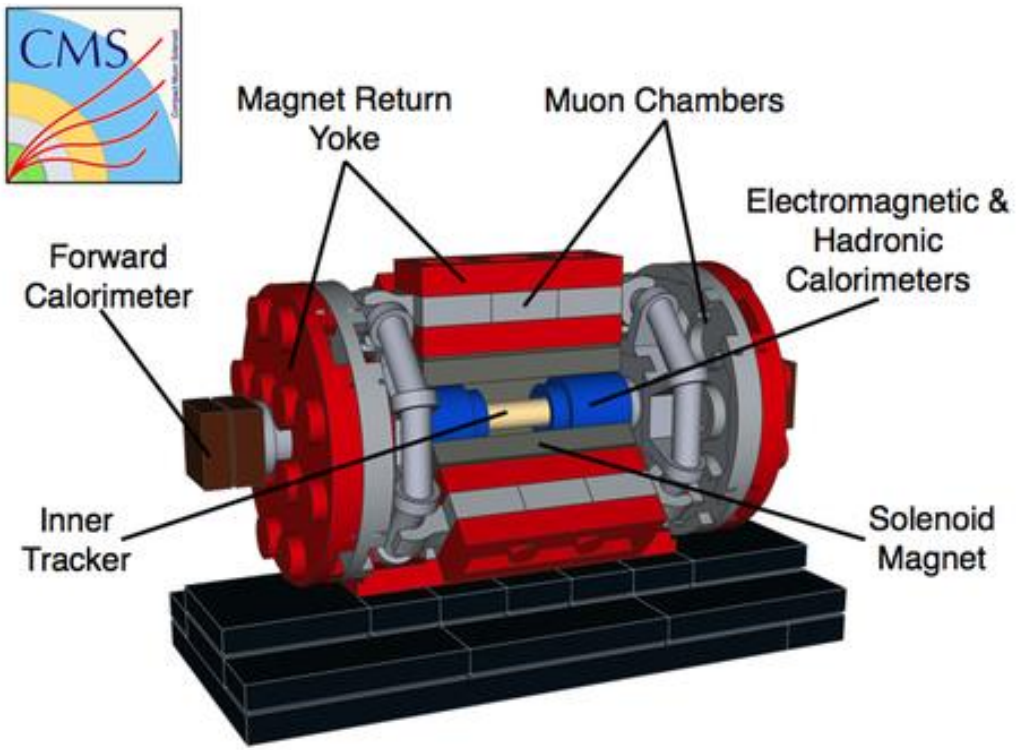
Outline of the lessons



CMS Experiment

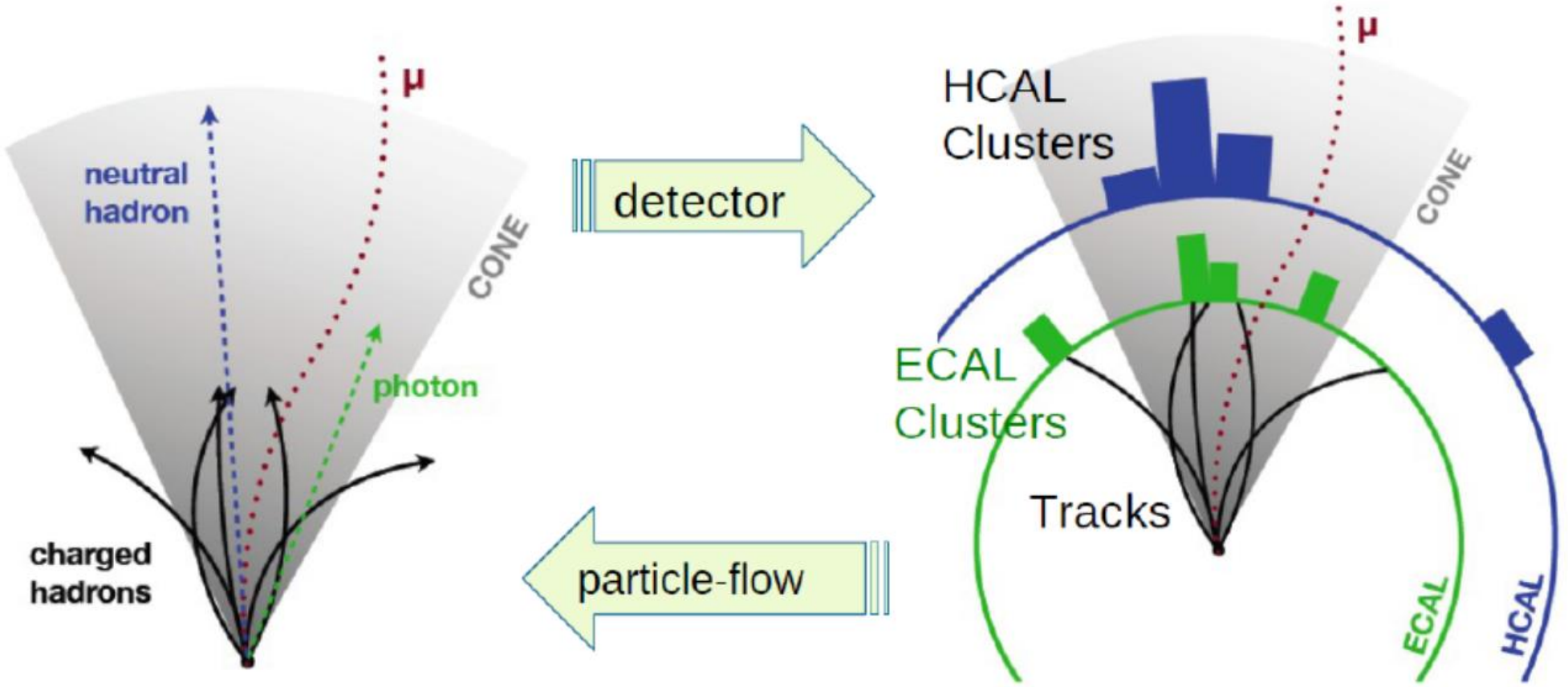
- Compact Muon Solenoid detector

1906	1036	1065	1110	281	229	51
PHD PHYSICISTS (1569 MEN, 337 WOMEN)	PHYSICS DOCTORAL STUDENTS (796 MEN, 240 WOMEN)	ENGINEERS (933 MEN, 132 WOMEN)	UNDERGRADUATES (824 MEN, 286 WOMEN)	TECHNICIANS	INSTITUTES	COUNTRIES & REGIONS



Particle Flow

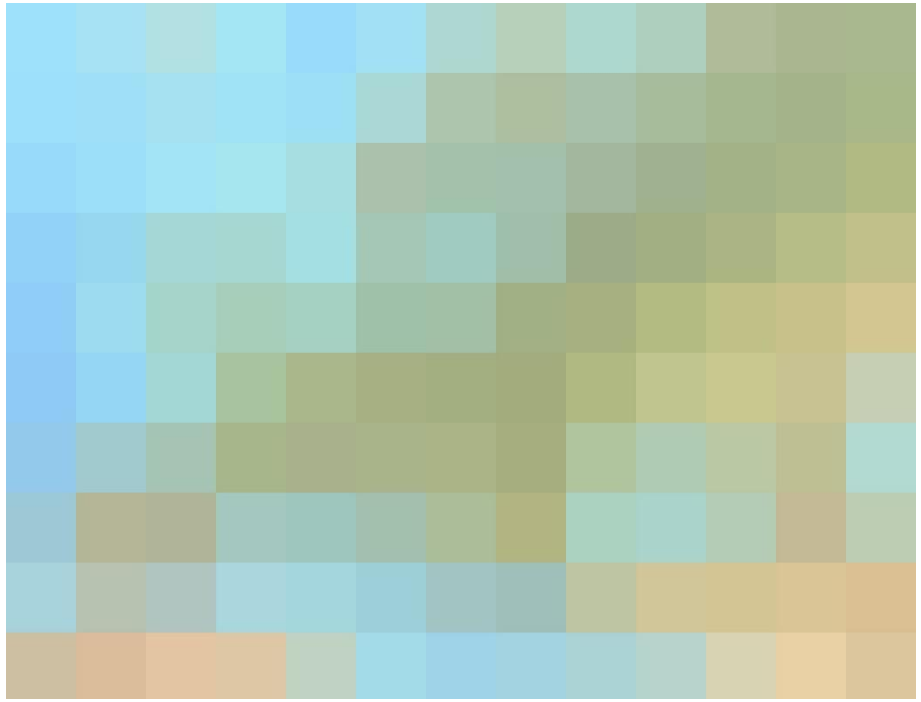
- Particles → pixelated detector energy/charge deposits → particle hypotheses



https://arxiv.org/abs/1706.04965

Particle Flow

- Human brains are pretty good at this task!



But with more diverse “data” it can get harder…

Particle Flow

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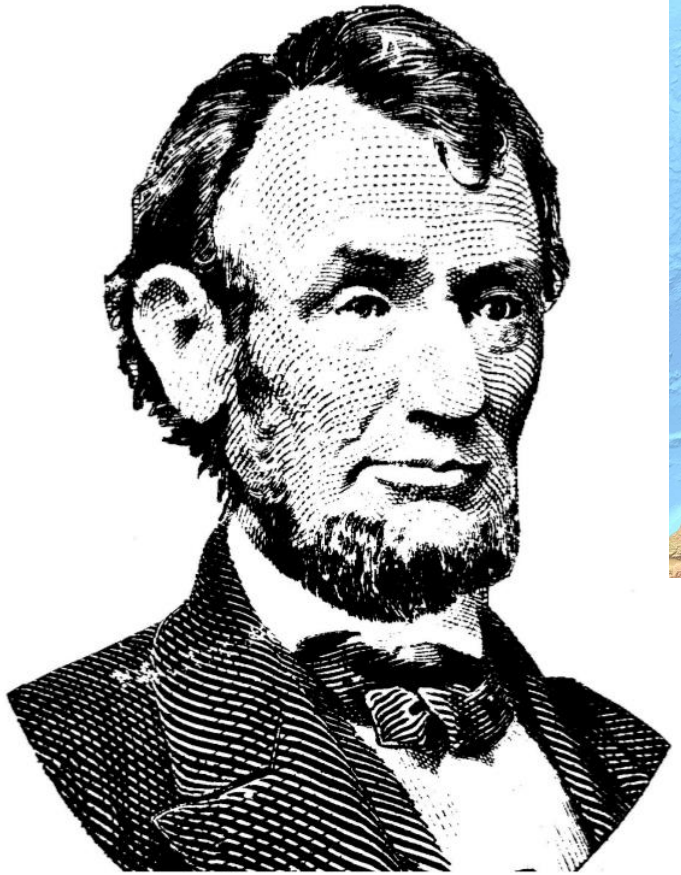
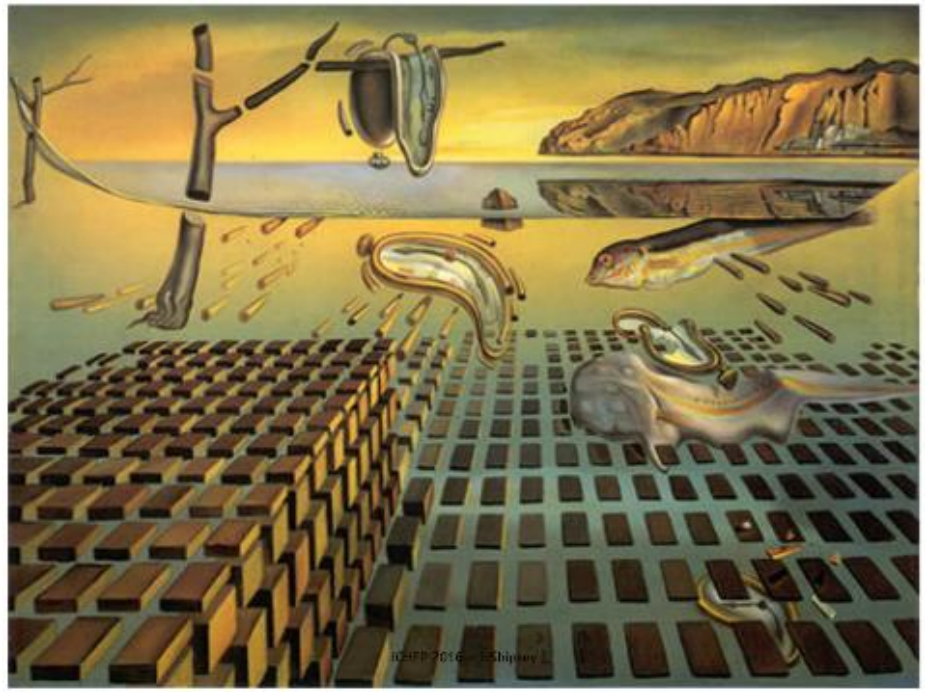


ICHEP 2016 -- I. Shipsey

But with more diverse “data” it can get harder…



Particle Flow

- Build amazing reconstruction algorithms
- Perfect the code and deploy it
- DON'T TOUCH IT!!
- **Result: many CMS graduate students know the words but not the physics!**

How well do you understand particle flow?

"What is particle flow?":	0%
"I know CMS uses it":	**50%**
"I get the basic concept":	**50%**
"I use particle flow fairly regularly":	0%

How well could you explain particle flow to a new graduate student?

"I could not explain it":	25%
"I could give a broad high-level overview":	**75%**
"I could describe the concept and how we use it":	0%
"I could pull up my cms-sw fork and get into details":	0%

Particle Flow

- What are your instincts about these questions?

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

A) electron
B) photon
C) neutron
D) muon

Three separate clusters in the ECAL are associated with one HCAL tower (the seed for each cluster is in front of the HCAL tower). Each cluster has over 5 GeV of energy, and the HCAL tower has 2 GeV of energy. When particle flow attempts to link objects together into a block (by using their physical proximity), 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 tower, none will be linked.

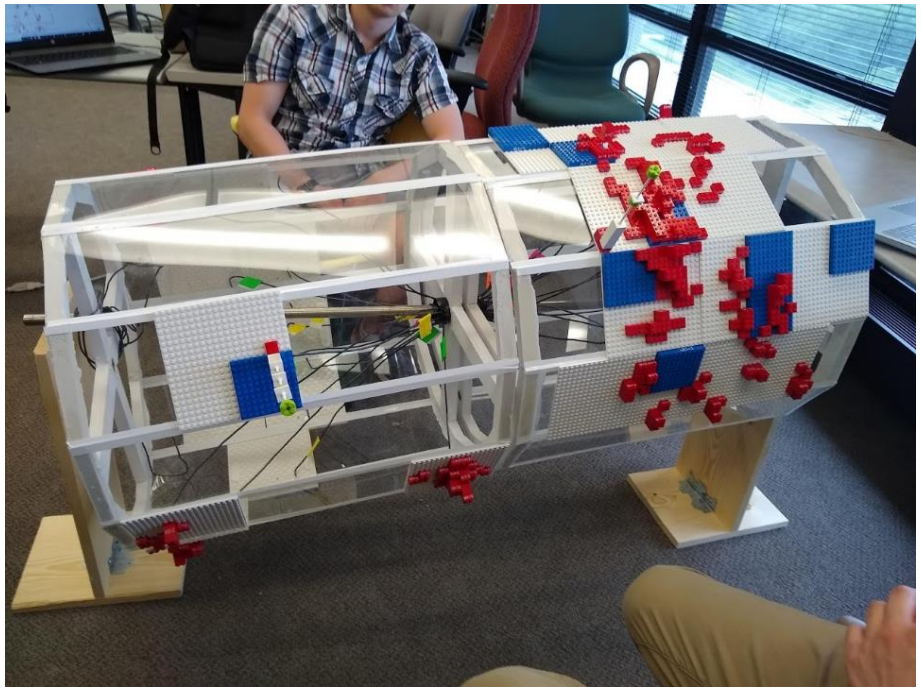
E) The lowest energy ECAL cluster will be linked with the HCAL, since that would be likely to be the closest energy match.

LEGO Particle Flow

- Fermilab hosts “Hands-on Advanced Tutorial sessions” (HATs) in summer
- Andrew Askew (FSU) and I wanted a REALLY hands-on tutorial apparatus!

Gen 1: 2018

Circular
String tracks
Base-10 height
Suitcase-sized
Single piece frame
Opaque

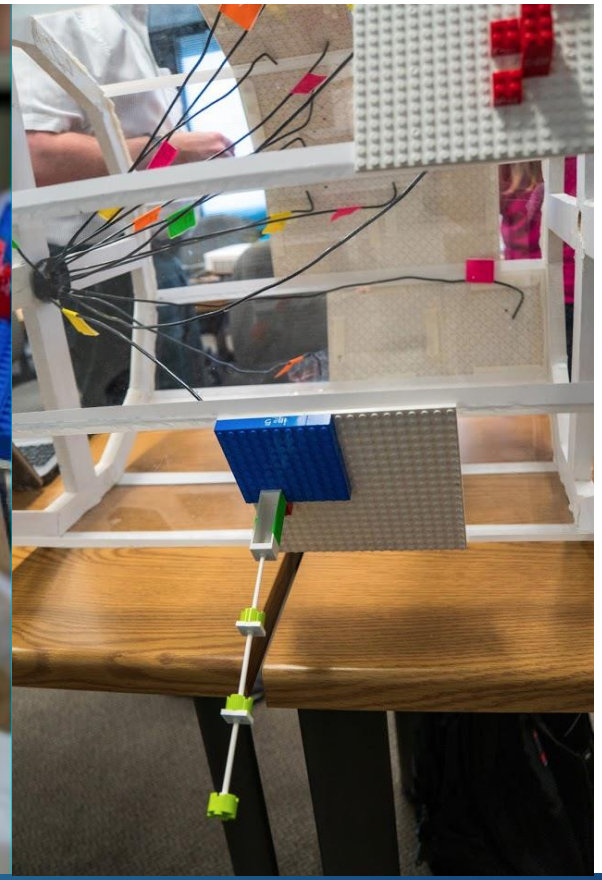


Gen 2: 2019

Piecewise circular
Curved wire tracks
Base-3 height
Car trunk sized
Two separable halves
Transparent

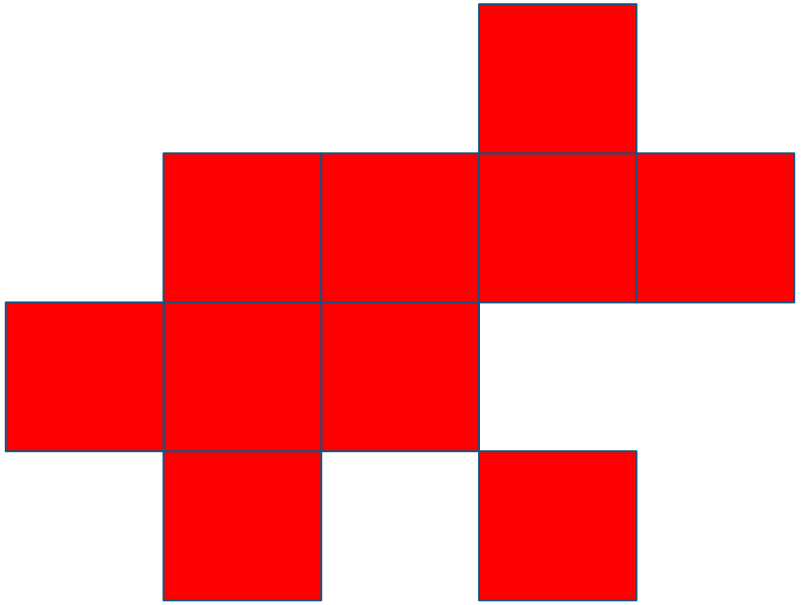
LEGO Particle Flow

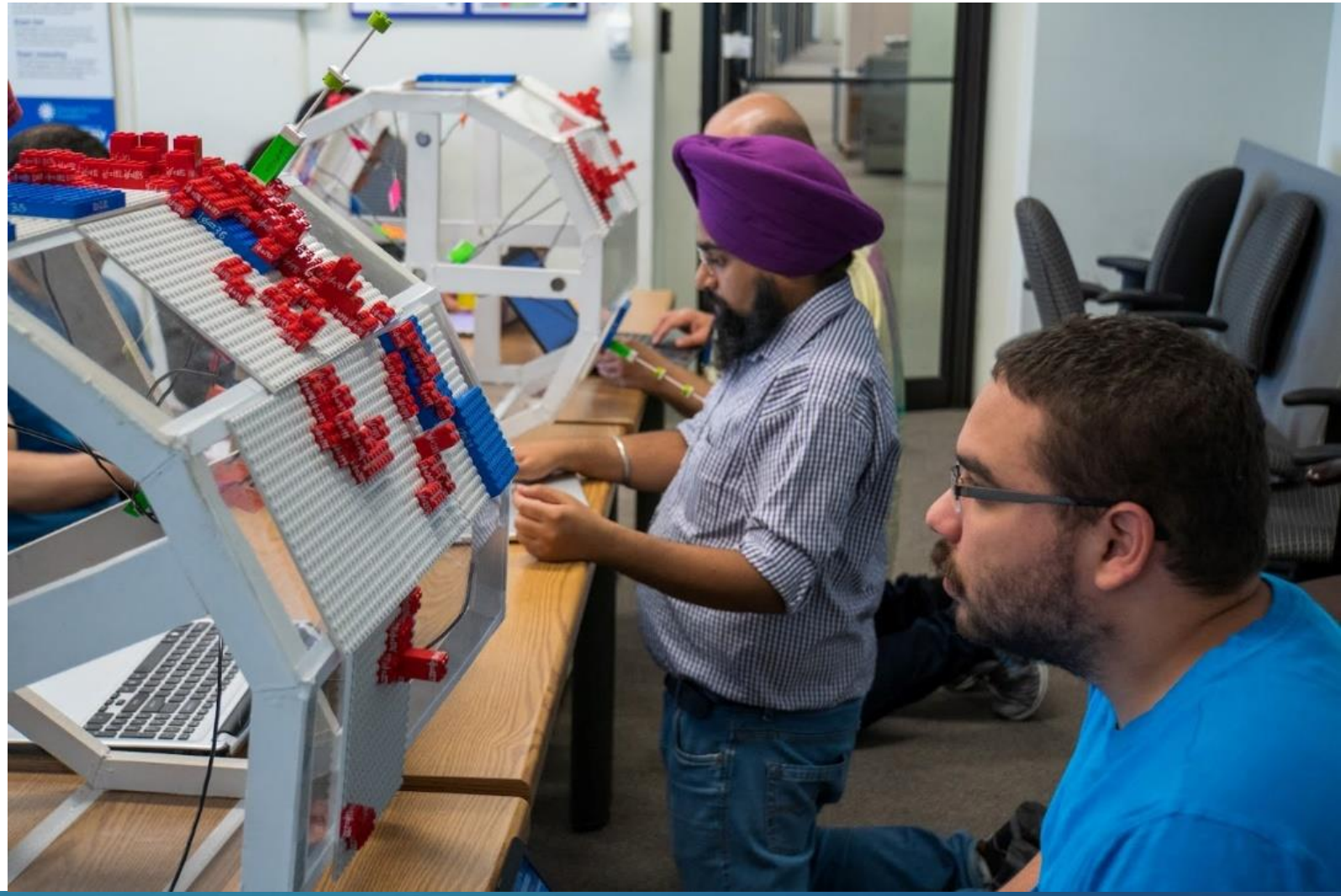
- Tracks = **12g black wire**. Curved by charge if momentum is < 2 GeV. Straight above that.
- Calorimeters = LEGO! **Red 2x2 ECAL** elements and **blue 10x10 HCAL** elements.
- Muons = LEGO! **Green 2x2 circles** for each chamber it hit (depth not to scale…)



LEGO Particle Flow

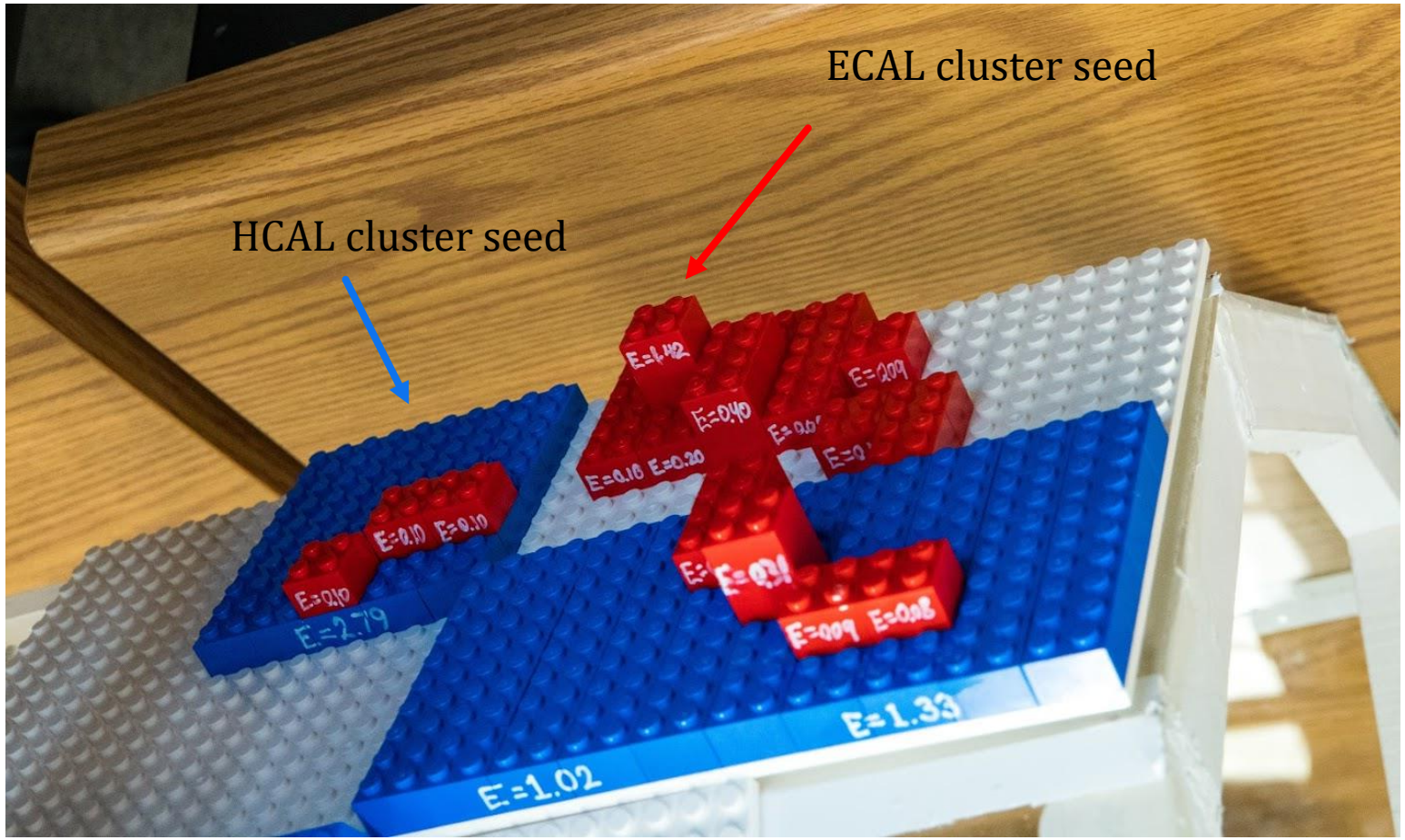
- Step 1: identify topological clusters by eye ("do any of my immediate neighbors have energy?")

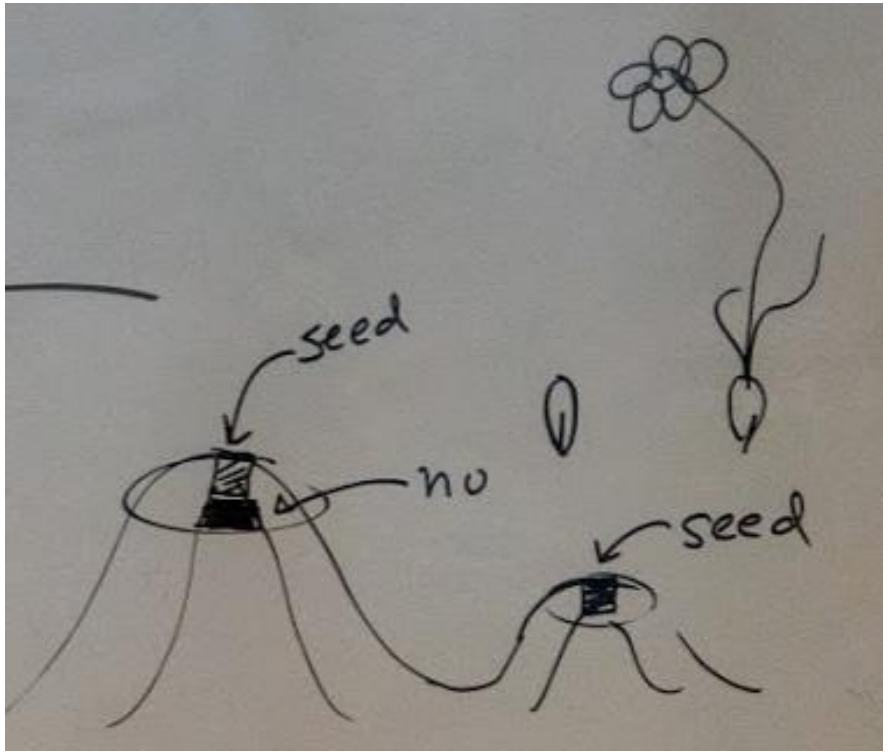




LEGO Particle Flow

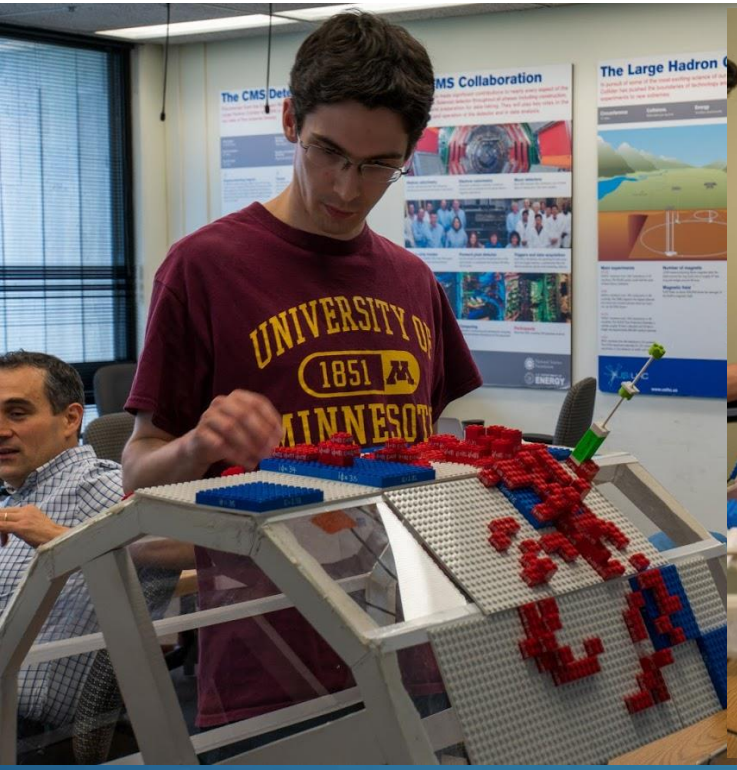
- Step 2: identify cluster seeds ("do I have more energy than any of my immediate neighbors?")
- Topological clusters can have more than one seed

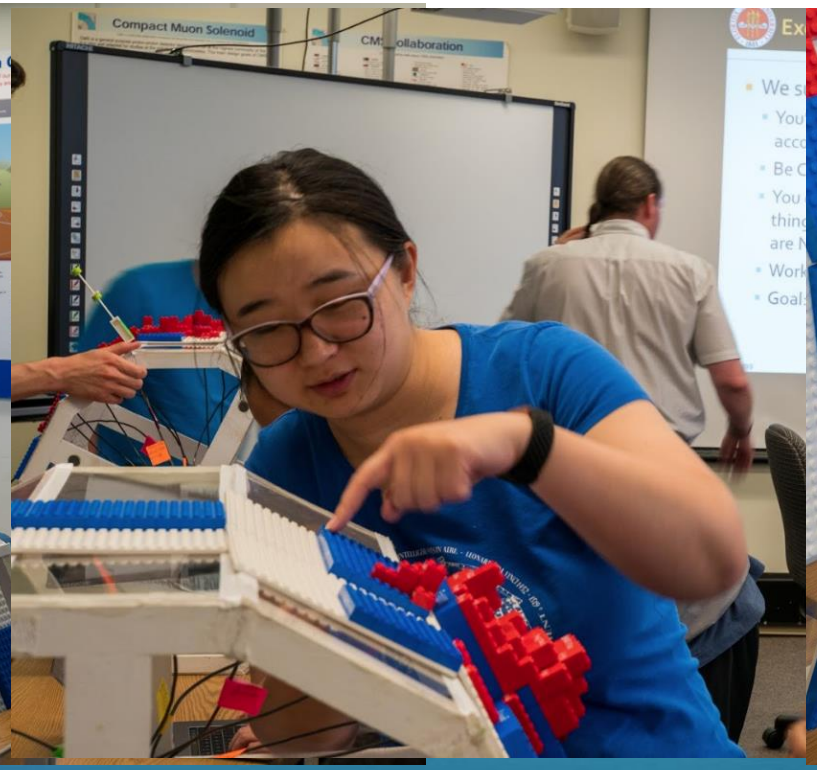


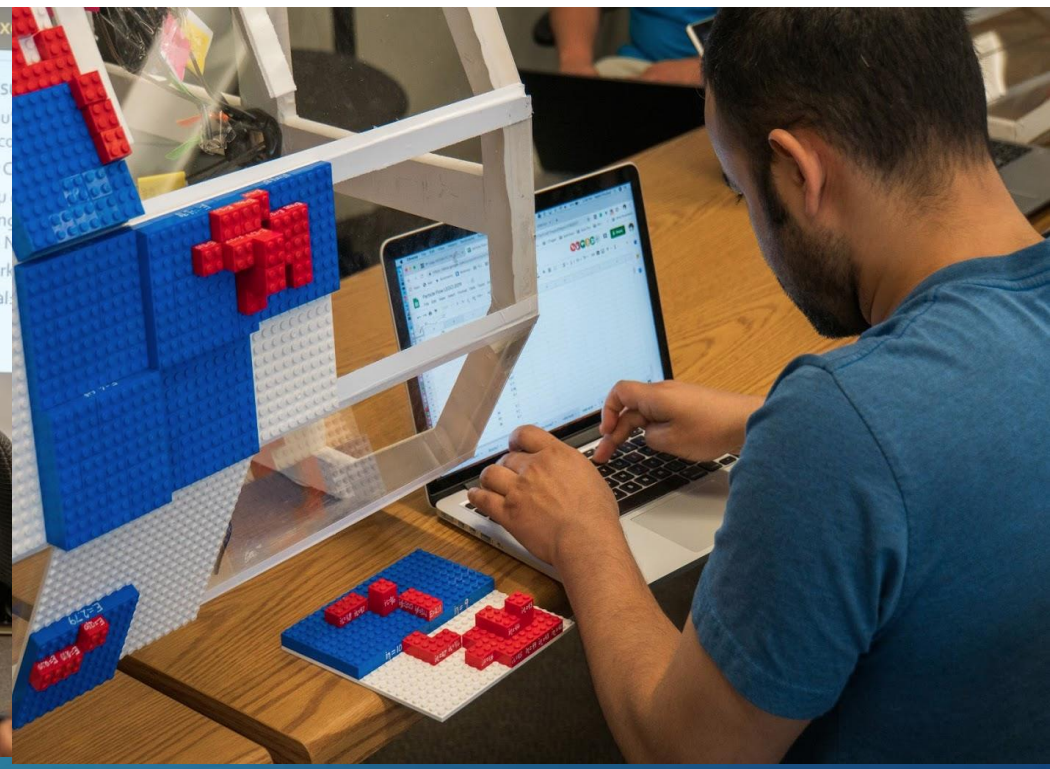


LEGO Particle Flow

- Step 3: identify cluster properties
- Iterative procedure with weight functions to determine how a hit shares its energy across clusters
- Students collected data off the LEGOs into a spreadsheet to perform these iterations
- **Final product after ~4 hours: list of ECAL and HCAL clusters with energies and positions**



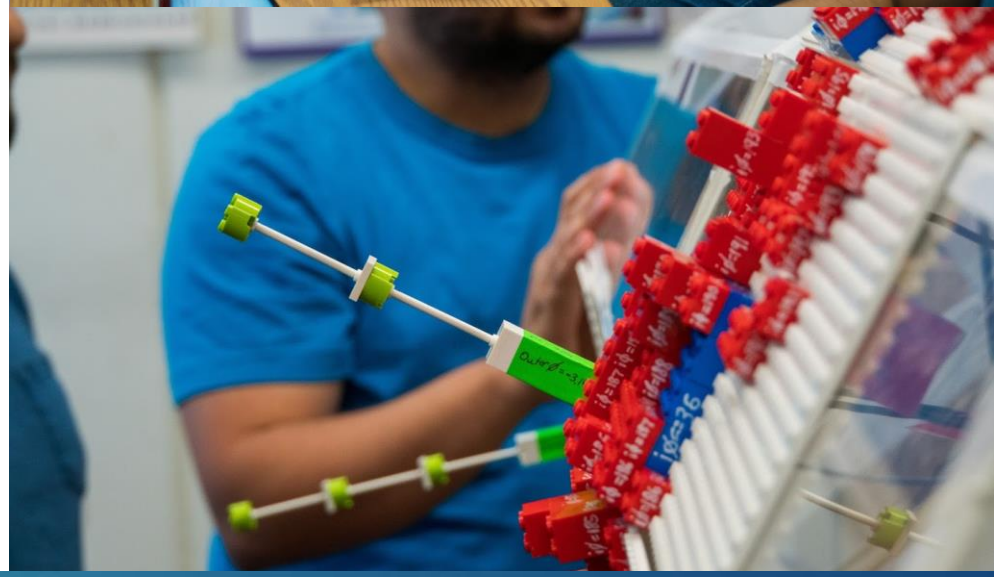




LEGO Particle Flow

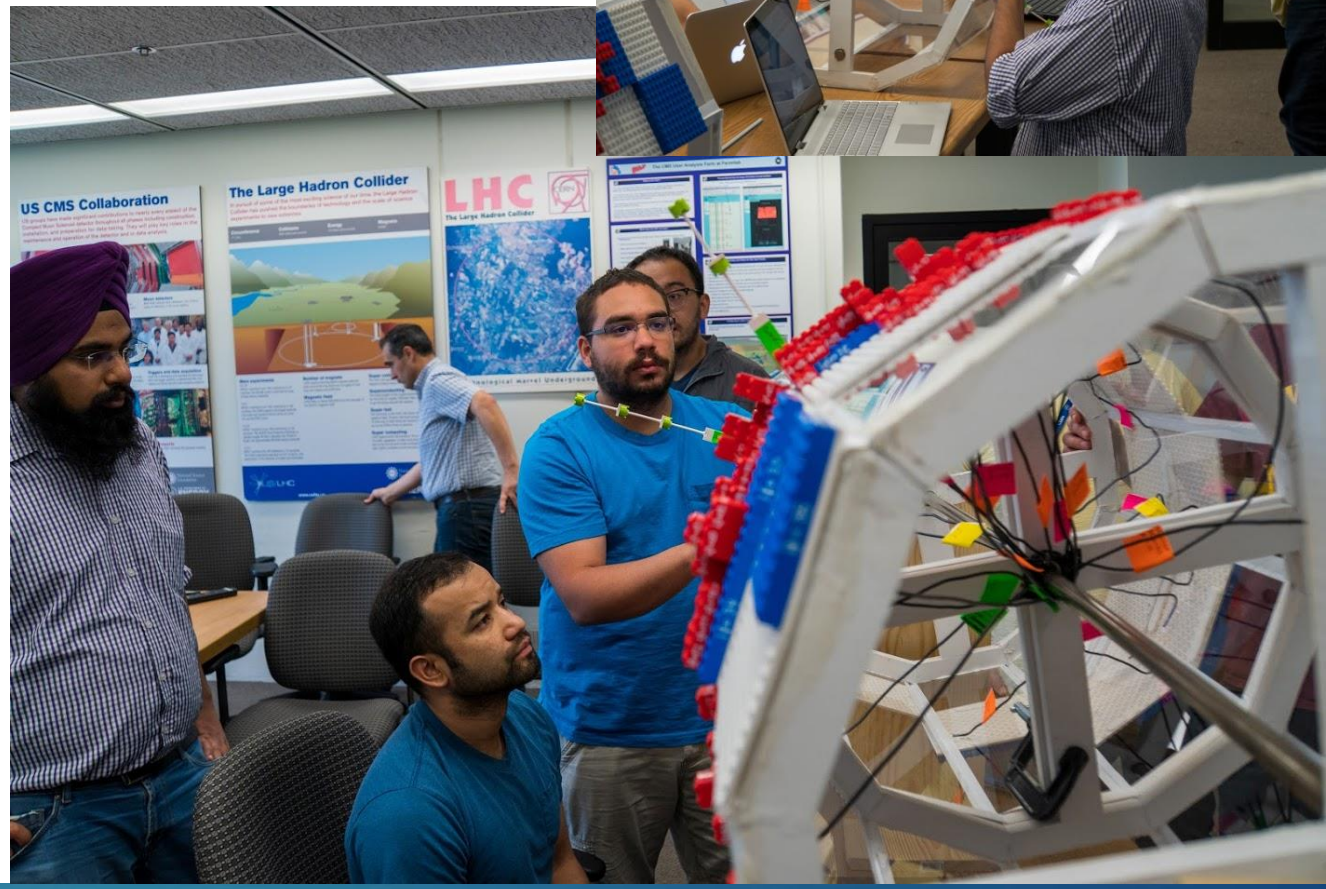
- Step 4: link clusters to each other and to tracks
  - Track – ECAL cluster
  - Track – HCAL cluster
  - Track – muon chamber track
  - ECAL cluster – HCAL cluster
  - …etc…
- Blocks are formed from links

- Examples:
  - HCAL cluster, 2 ECAL clusters, 3 tracks
  - ECAL cluster, 1 track
  - HCAL cluster, ECAL cluster, 1 track, 1 muon chamber track



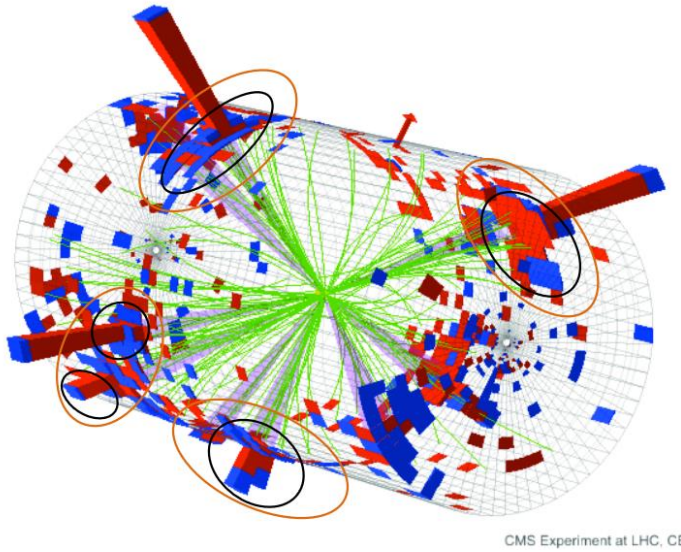
LEGO Particle Flow

- Step 5: particle hypotheses and energy corrections
  - Muons (muon track + directly-linked clusters/tracks)
  - Isolated electrons (ECAL + track) and photons (ECAL, no track)
  - Neutral hadrons (track-free HCAL or H+ECAL)
  - Charged hadrons (everything else)
  - Rules for defining energy particle and calibrating it
- Examples:
  - HCAL, 2 ECAL, 3 tracks → 3 charged hadrons
  - ECAL, 1 track → 1 electron
  - HCAL, ECAL, 1 track, 1 muon track → 1 muon
- **End with list of muons, electrons, photons, charged hadrons, and neutral hadrons**



Using particle flow

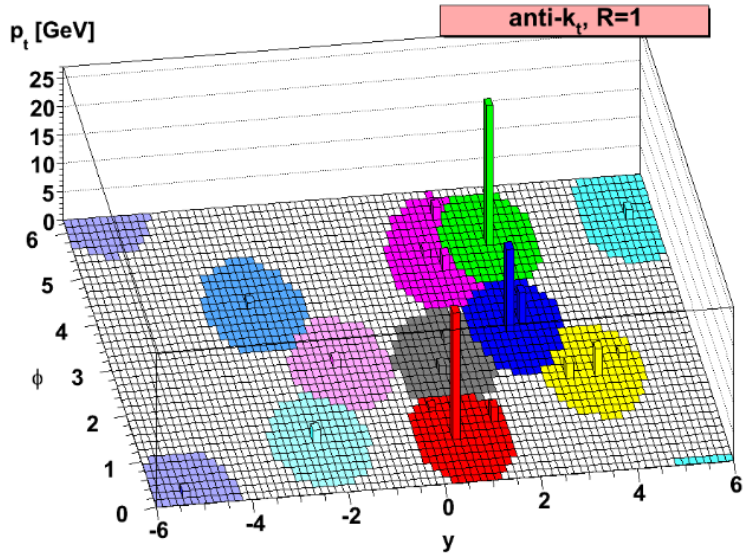
- Particle flow particles ("candidates") are the foundation of CMS physics objects
  - Muons, electrons, photons are already candidates
  - Tau leptons, jets, and missing transverse momentum can be defined using candidates
- Interpreting the event
  - Taus identified with a series of custom algorithms
  - Candidates can be clustered together into **"jets"**, mostly containing hadrons & photons
  - Missing transverse momentum = negative vector sum of candidates' momenta



Combine particles i and j until:

$$p_{T,i}^{-2} > \min\left(p_{T,i}^{-2}, p_{T,j}^{-2}\right)\Delta R_{ij}^2/R^2$$

High momentum particles grouped first



Enjoy the hands-on lesson & colloquium!