High Energy Physics (HEP) Overview

Most slides taken from previous Quarknet presentations, particularly Jeremy's from 2020!

What are we looking at?

Event	XY Radius (cm)	Length Z (cm)	cos theta x	cos theta y	cos theta z	Sum E-Cal	Muon Tag
50001	-1808.48	20994.94	0.47	-0.10	-0.88	9127.05	
50001	1808.48	20994.93	-0.47	0.10	0.88	9127.05	
50002	-2801.12	16128.99	-0.21	-0.71	0.68	0.00	Hit
50002	2801.12	16128.99	0.21	0.71	-0.68	0.00	Hit
50003	-2959.26	14972.58	0.17	-0.76	-0.63	0.00	
50003	2894.38	15465.20	-0.39	0.65	0.65	0.00	
50004	-63.16	23869.40	-0.01	-0.01	-1.00	9140.57	
50004	63.16	23869.40	0.01	0.01	1.00	9140.57	
50005	-2245.86	19255.54	-0.59	0.00	0.81	0.00	
50005	2811.81	16055.31	0.64	0.36	-0.67	0.00	
50006	-3799.30	219.73	0.51	0.86	0.01	9129.13	
50006	3799.30	219.73	-0.51	-0.86	-0.01	9129.13	
50007	-3389.30	10788.96	0.03	0.89	-0.45	0.00	Hit
50007	3389.30	10788.95	-0.04	-0.89	0.45	0.00	Hit
50008	-2988.41	14742.48	0.73	-0.29	0.62	9120.09	
50008	2988.41	14742.48	-0.73	0.29	-0.62	9120.09	

What are we measuring and how do we understand what we see?

What are the learning goals?

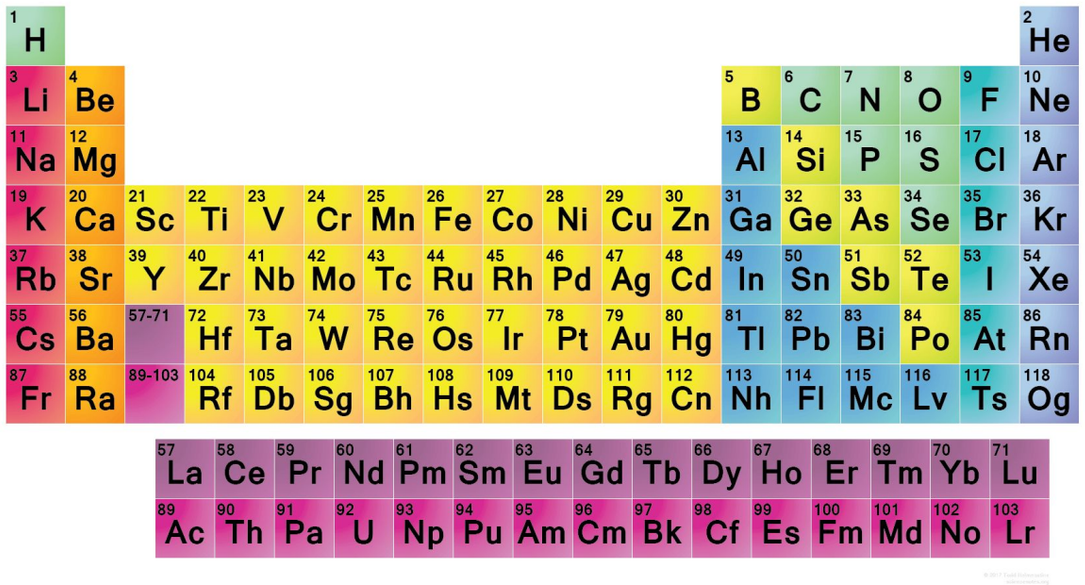
What is particle physics? 1

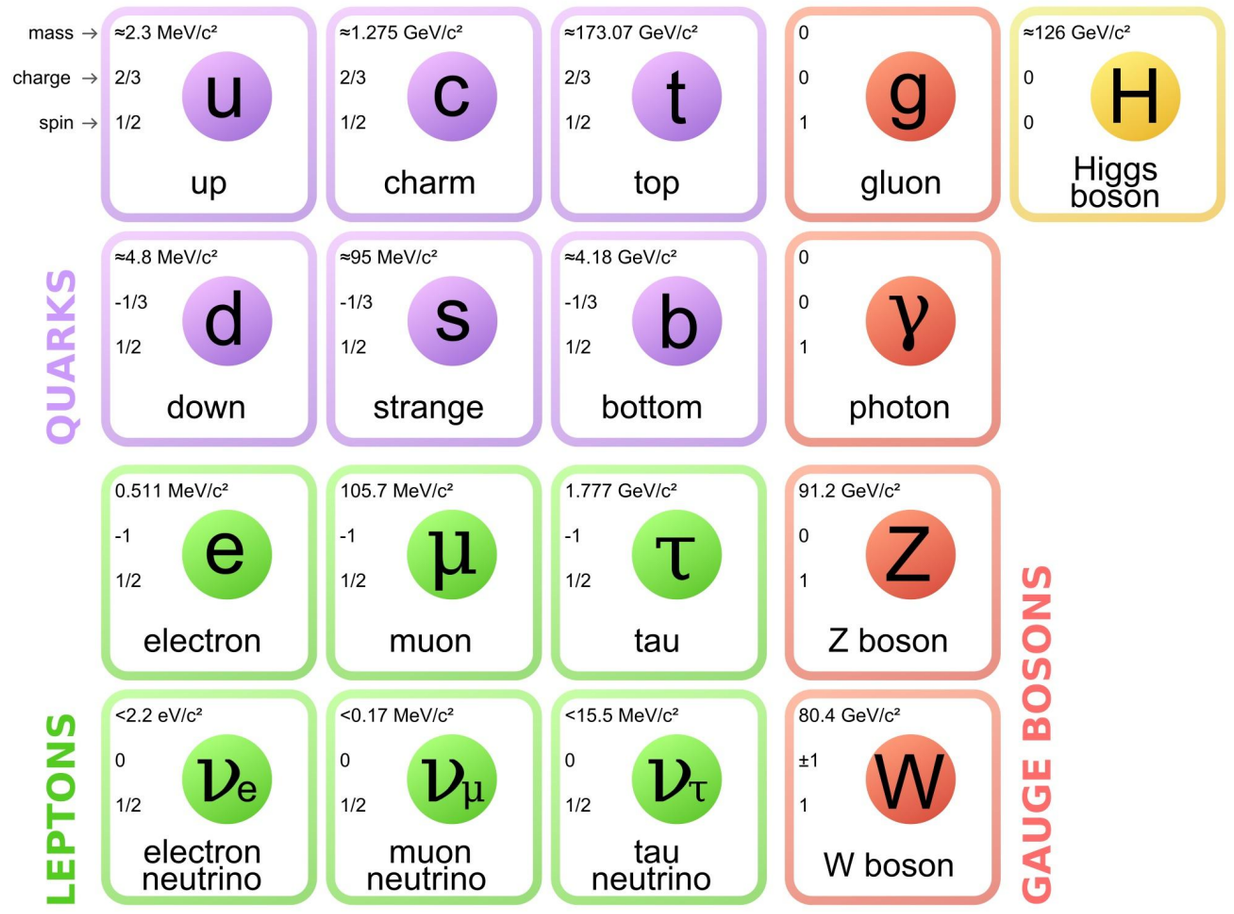
How do particle detectors work? 2

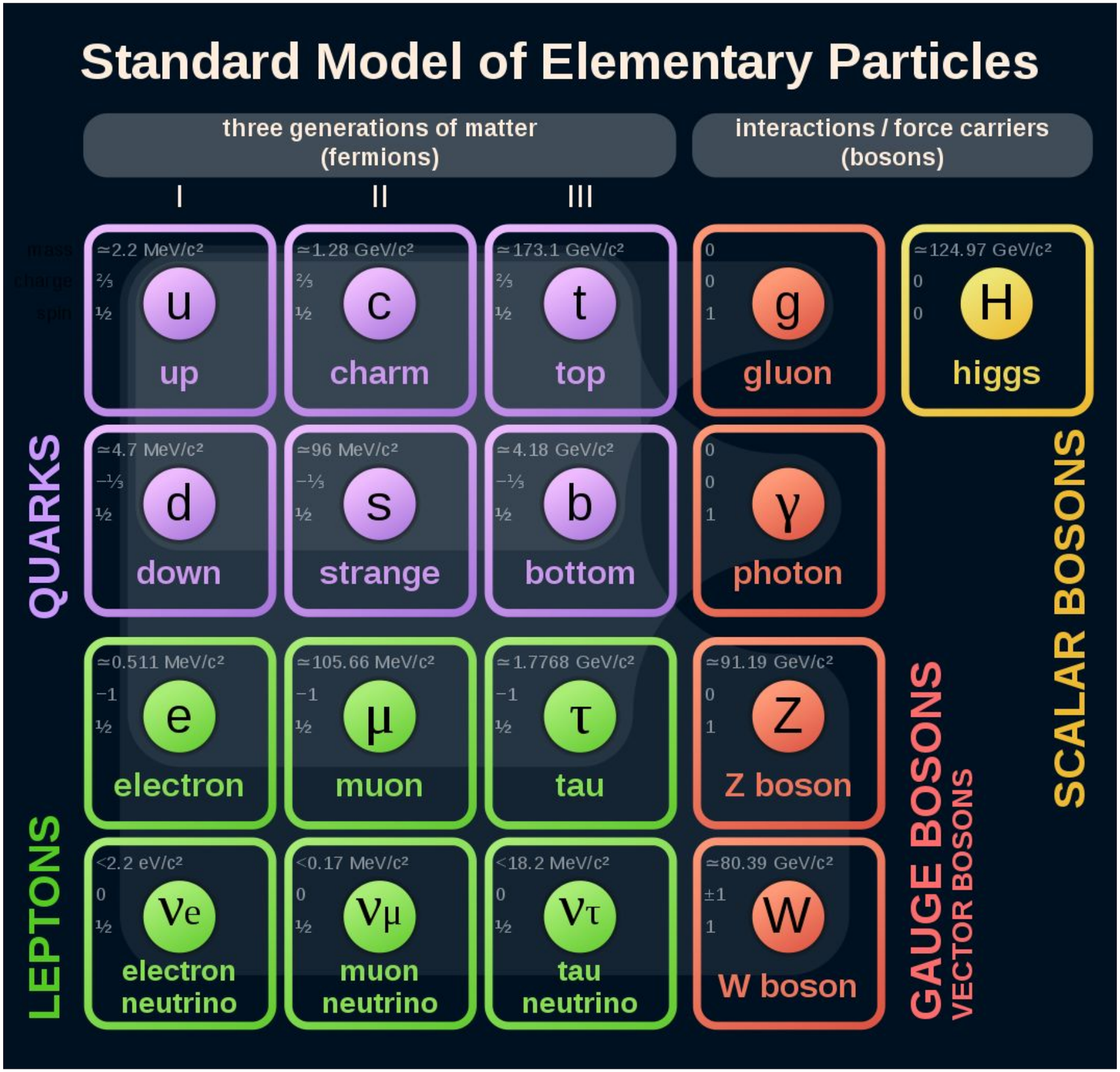
What are we seeing in the detectors? 3

How do we analyze the data? 4

The Standard Model





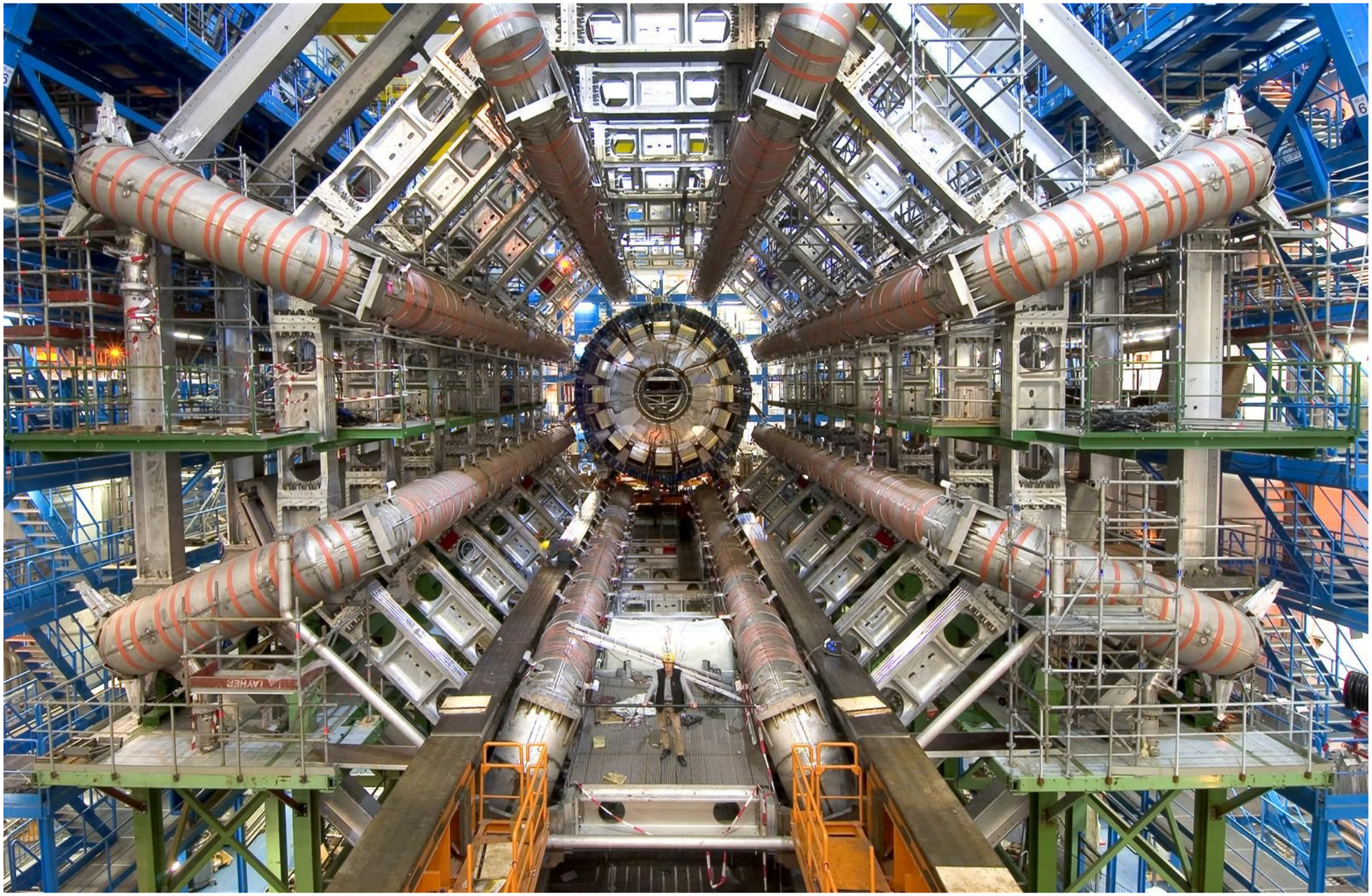

Standard Model of Elementary Particles
three generations of matter (fermions)
interactions / force carriers (bosons)
I
II
III
mass
charge
spin
≃2.2 MeV/c²
⅔
½
u
up
≃1.28 GeV/c²
⅔
½
c
charm
≃173.1 GeV/c²
⅔
½
t
top
0
0
1
g
gluon
≃124.97 GeV/c²
0
0
H
higgs
≃4.7 MeV/c²
−⅓
½
d
down
≃96 MeV/c²
−⅓
½
s
strange
≃4.18 GeV/c²
−⅓
½
b
bottom
0
0
1
γ
photon
QUARKS
≃0.511 MeV/c²
−1
½
e
electron
≃105.66 MeV/c²
−1
½
μ
muon
≃1.7768 GeV/c²
−1
½
τ
tau
≃91.19 GeV/c²
0
1
Z
Z boson
GAUGE BOSONS
VECTOR BOSONS
SCALAR BOSONS
<2.2 eV/c²
0
½
νe
electron neutrino
<0.17 MeV/c²
0
½
νμ
muon neutrino
<18.2 MeV/c²
0
½
ντ
tau neutrino
≃80.39 GeV/c²
±1
1
W
W boson
LEPTONS

There’s more! Resources:

- Particle Adventure (good resource for students)
- Hyperphysics particle physics topics (medium difficulty between these two resources)
- Particle Data Group PDG (detailed resource, includes pamphlet you can order or use interactive online version)

*thanks Jeremy for researching these!

The LHC and New Physics



 ATLAS detector

Generic Particle Detector

Cylinders wrapped around the beam pipe

From inner to outer . . .

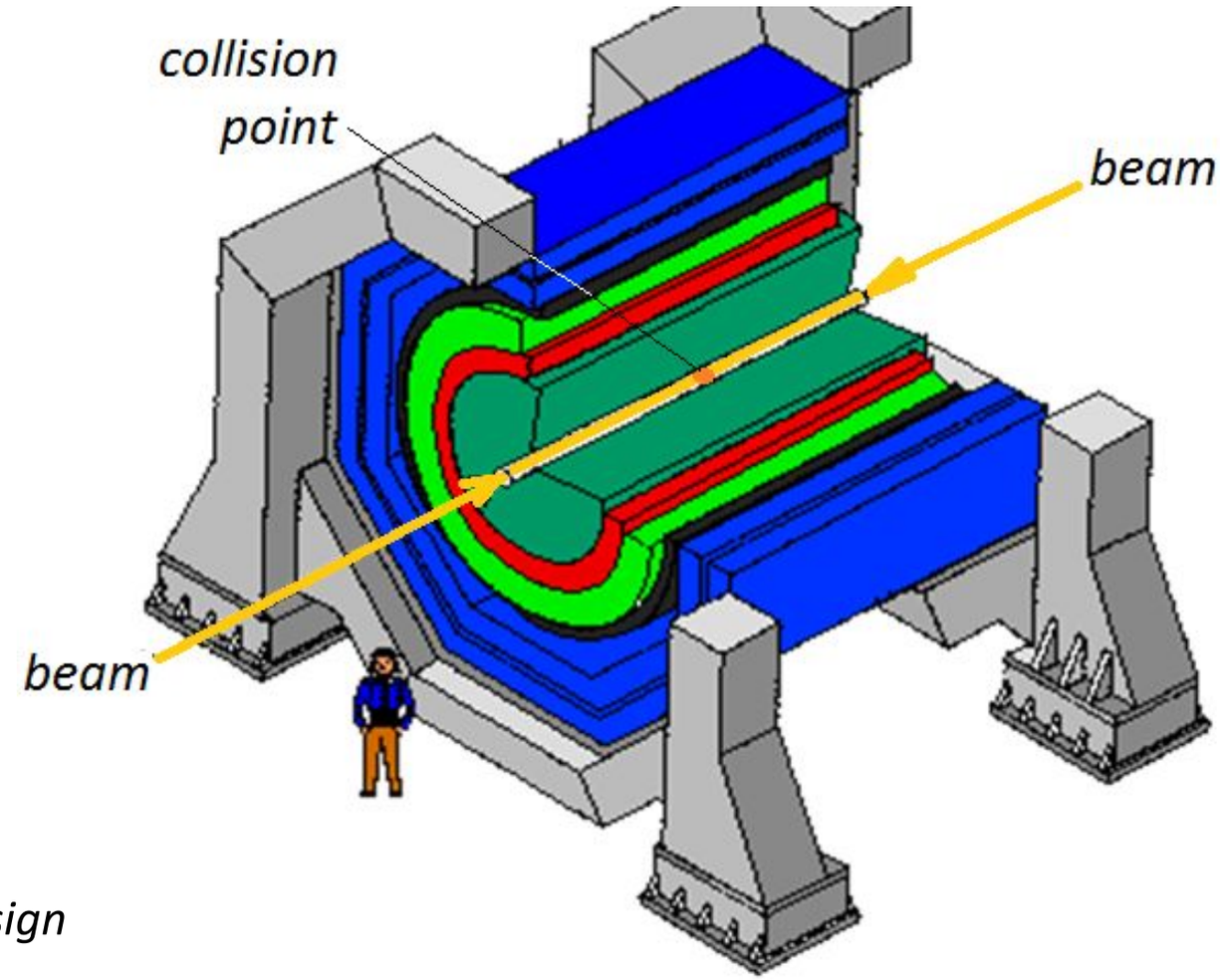
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

Magnet*

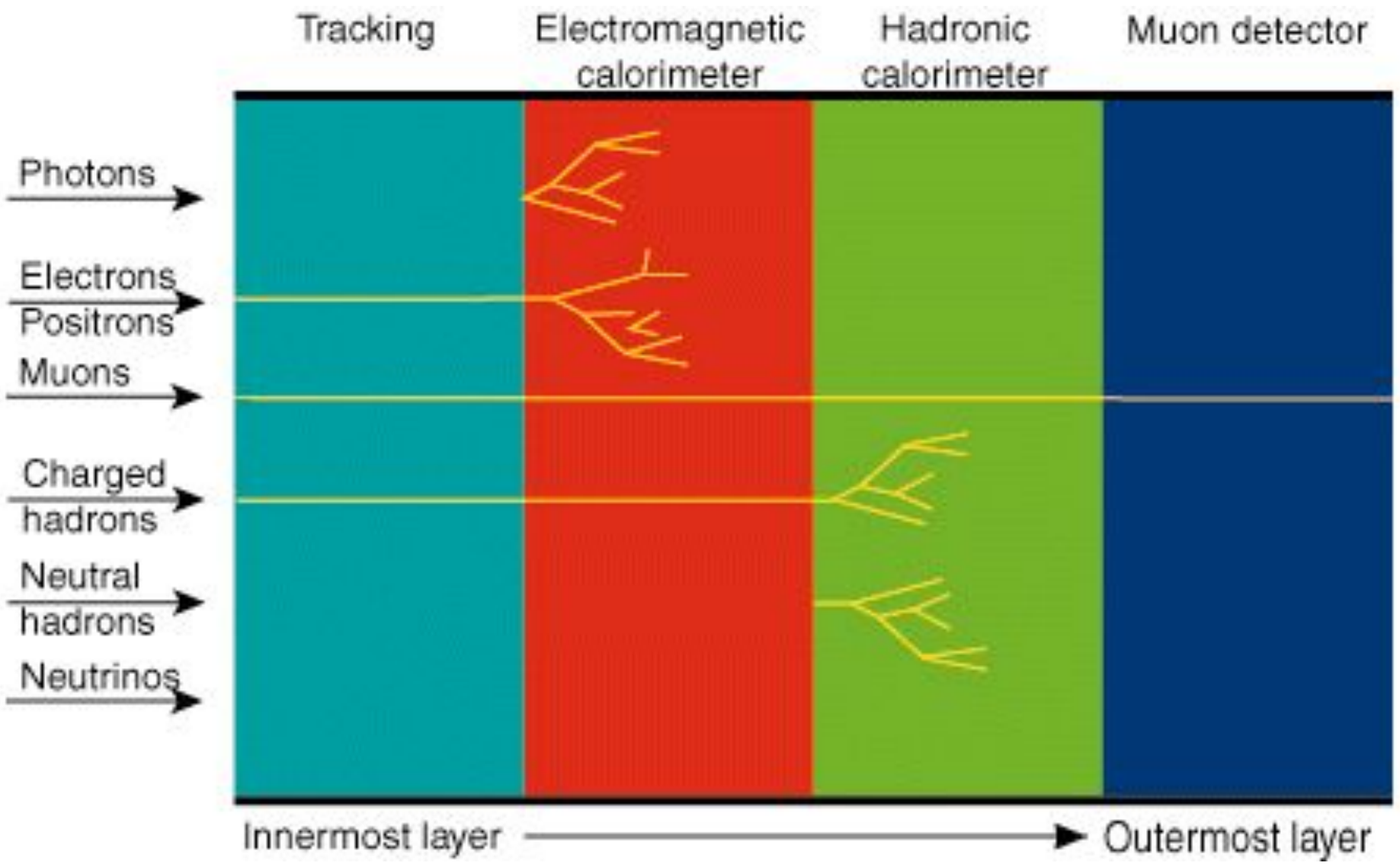
Muon chamber



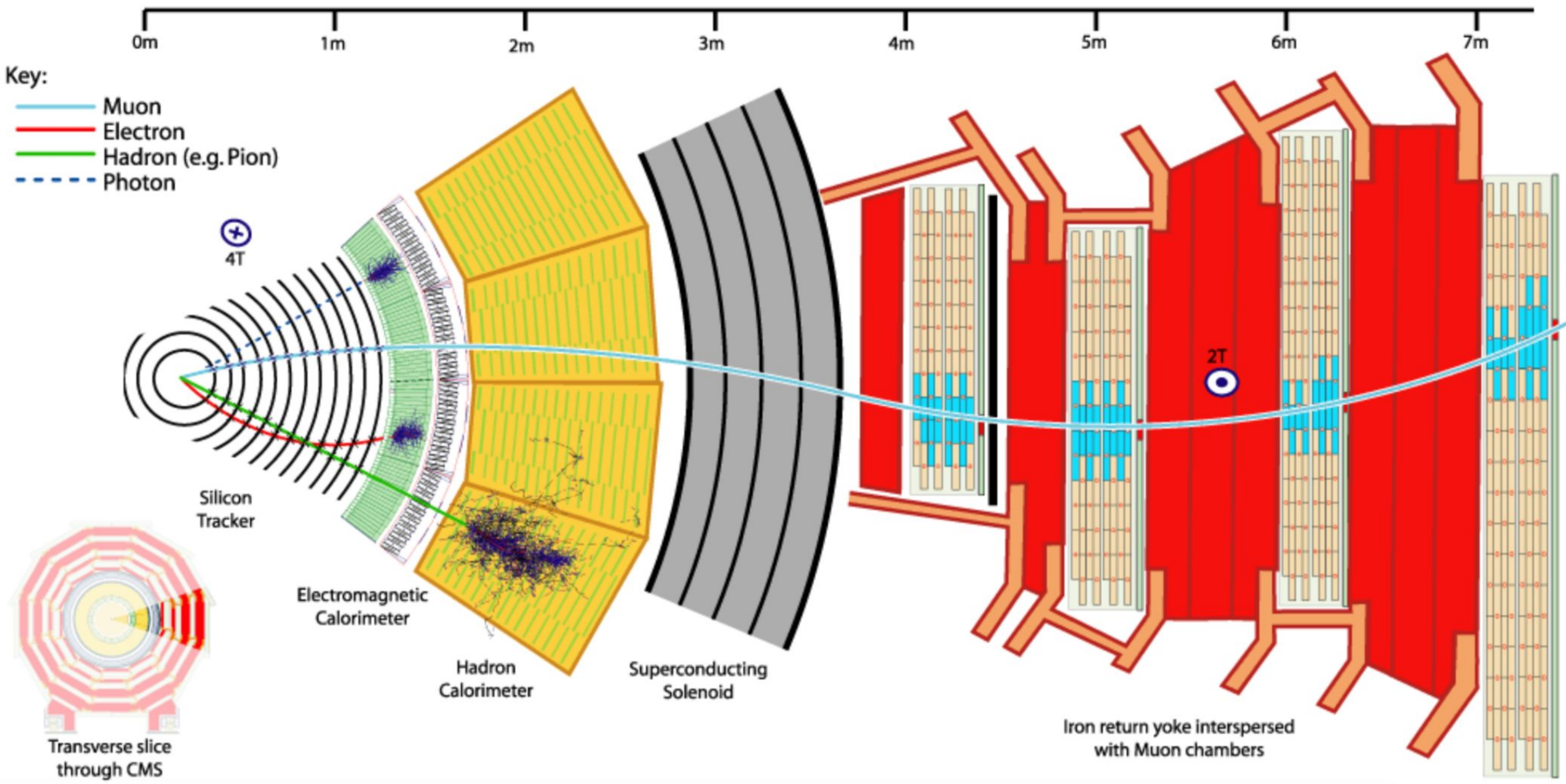
* *location of magnet depends on specific detector design*

Detector Tracks

All detectors have 4 basic layers



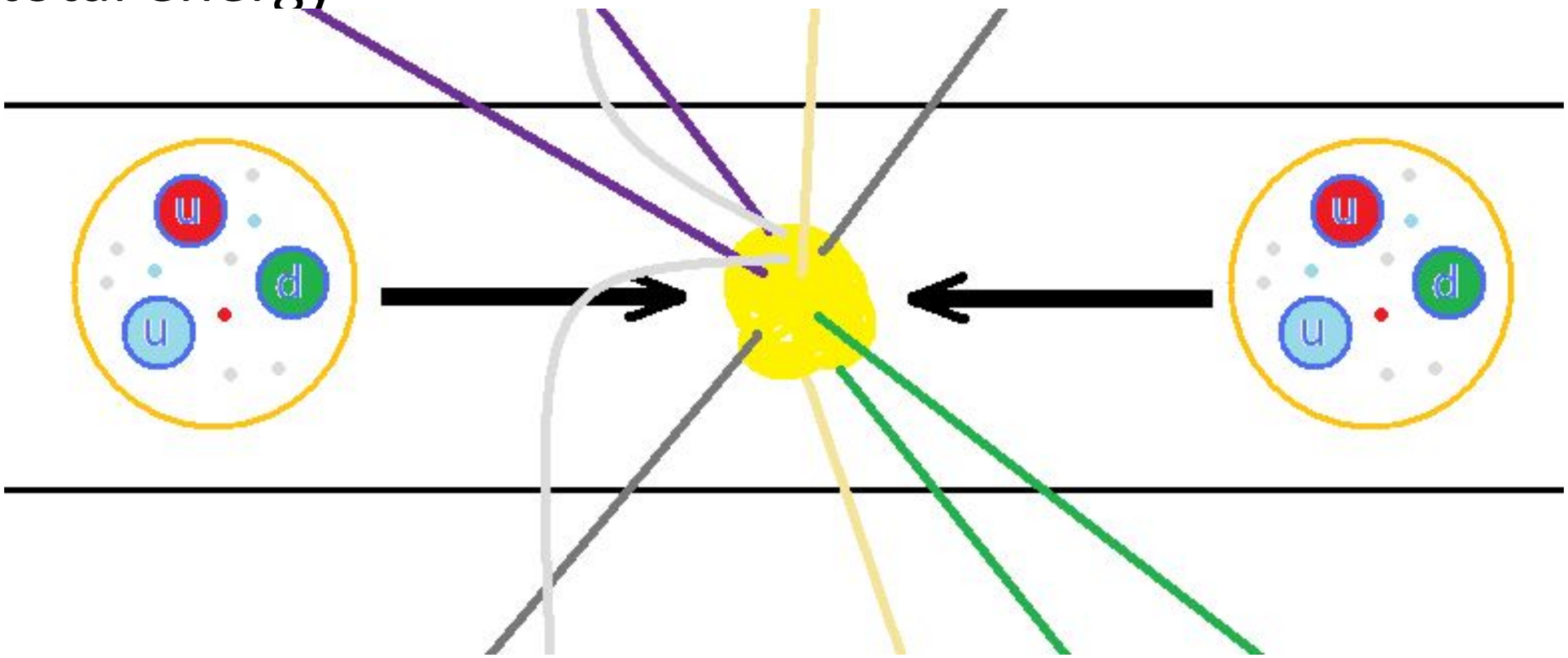
Detector Tracks



Energy & Particle Mass

If each beam proton has energy 4 TeV....

- The total collision energy is 2 x 4 TeV = 8 TeV
- Each particle inside a proton shares only a portion
- A newly created particle's mass ***must be*** smaller than the total energy



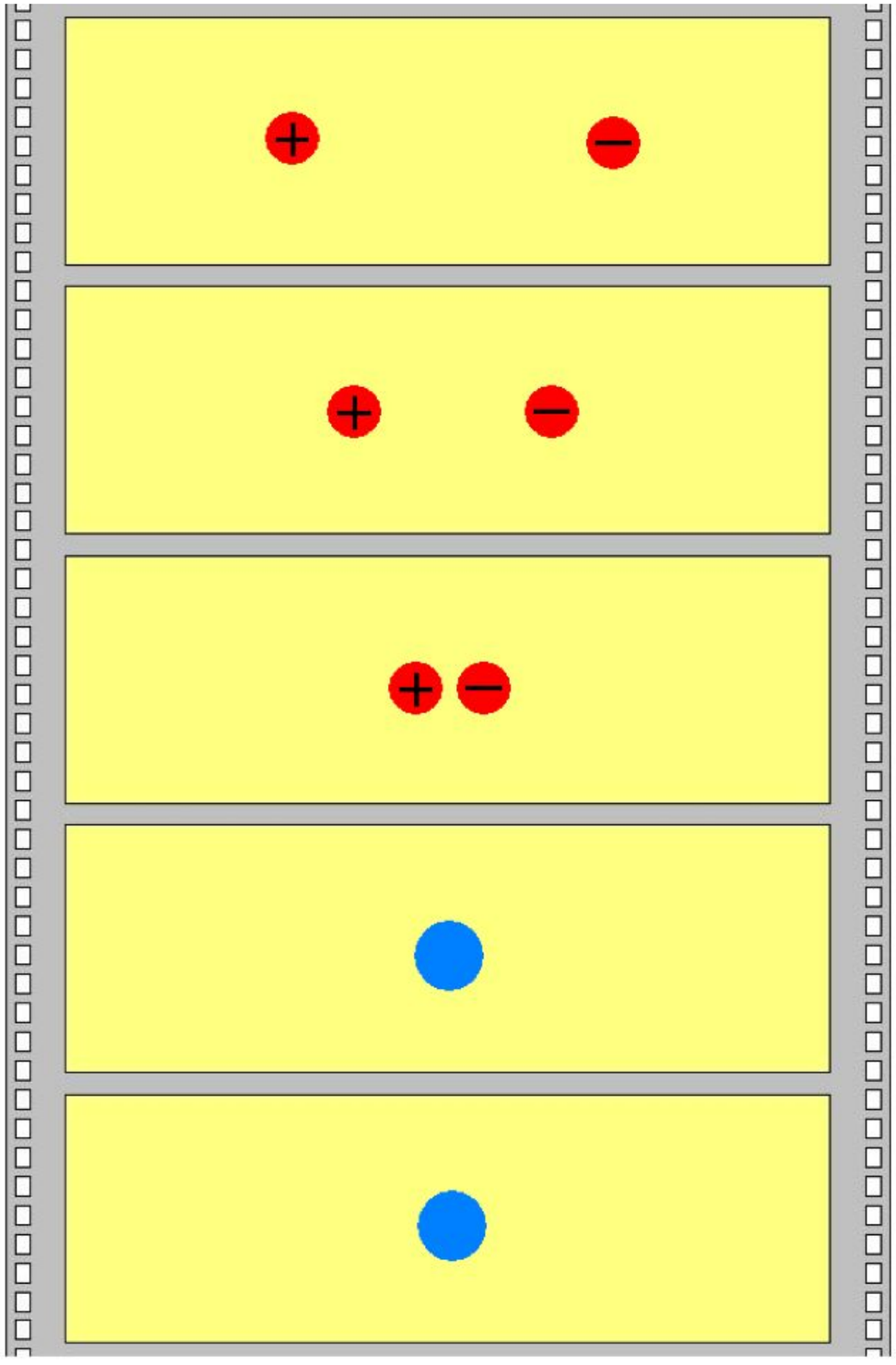
Particle Decays

The collisions create new particles that promptly decay.

Decaying particles *always* produce lighter particles.

Conservation laws allow us to see patterns in the decays.

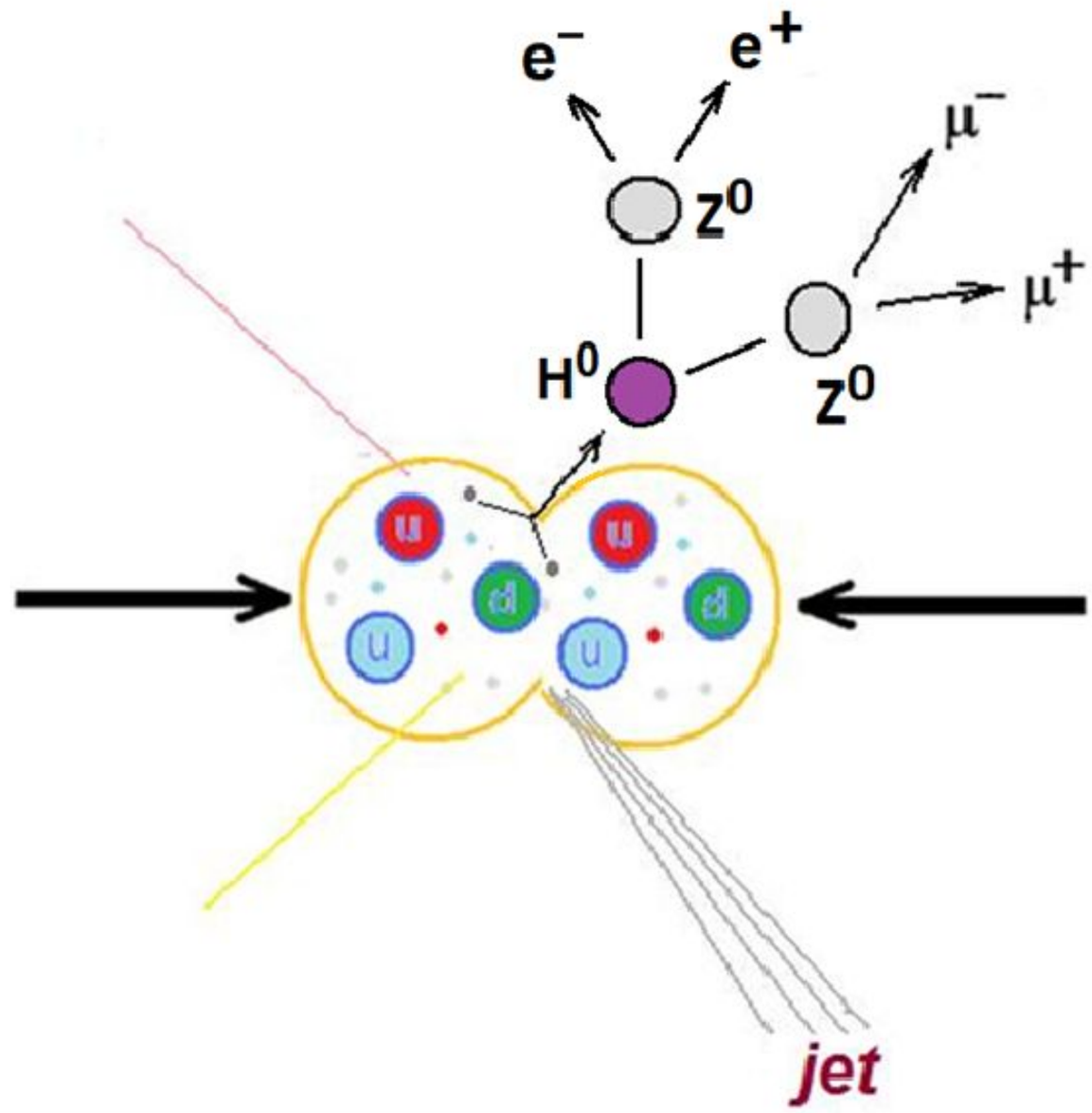
Ex) neutral, large blue decays into net neutral, smaller reds



Higgs Particle Production

The Higgs boson decays into daughter particles, sometimes including muons.

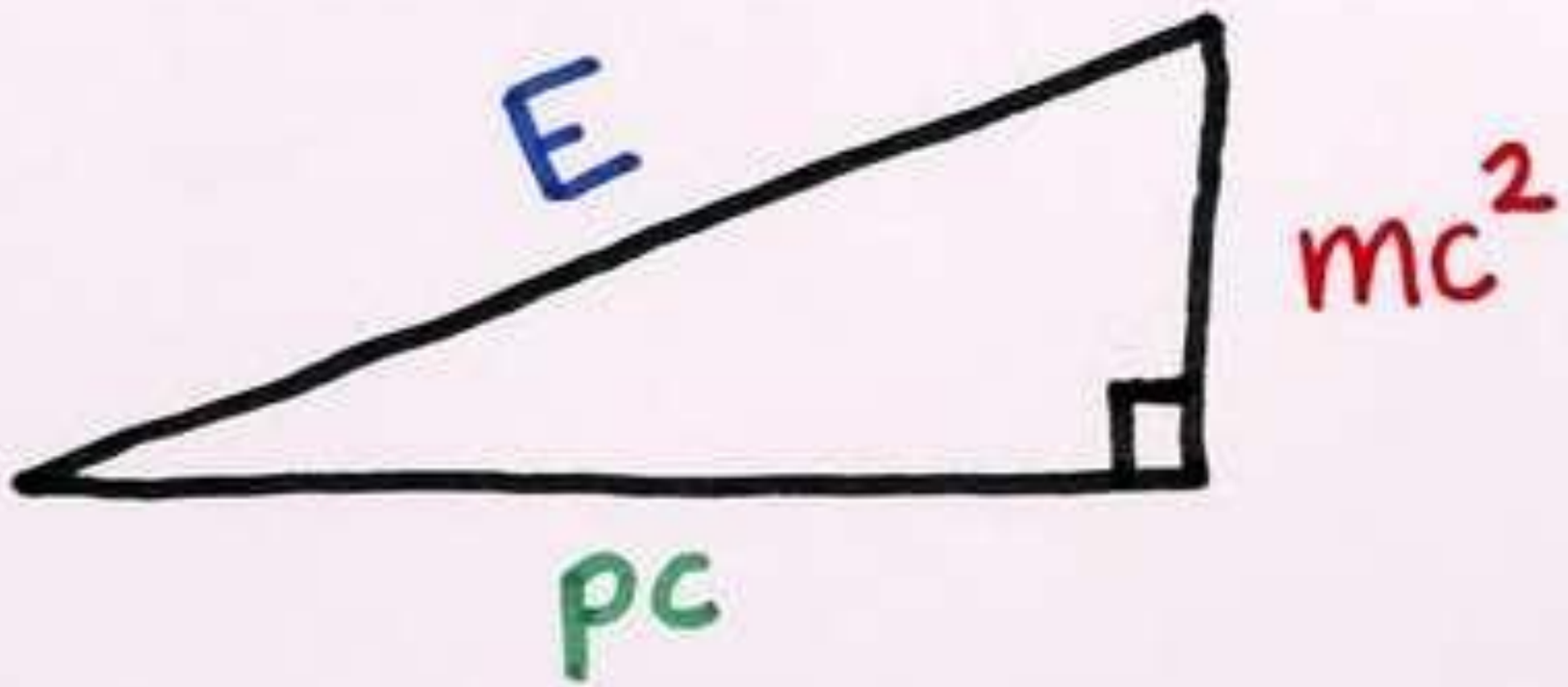
Other particles also produce muons, such as the Z boson.



Still more resources!

CERN detector overview, good for students

Detailed presentation on detector physics, includes historical overview
https://www.desy.de/~garutti/LECTURES/ParticleDetectorSS12/L1_Introduction_HEPdetectors.pdf



$$E^2 = (mc^2)^2 + (pc)^2$$

A Word About Units

Qty	Formula	SI Unit	HEP Unit
Energy	$K \sim mv^2$	Joule	GeV
Mom.	p=mv	J/speed	GeV/c
Mass	m	J/speed^2	GeV/c^2

Make c = 1 and E = p = m, everything in GeV

The famous Einstein relationship for energy

$$E = mc^2$$

can be blended with the relativistic momentum expression

$$p = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}}$$

to give an alternative expression for energy.

The combination **pc** shows up often in relativistic mechanics. It can be manipulated as follows:

$$p^2c^2 = \frac{m_0^2 v^2 c^2}{1 - \frac{v^2}{c^2}} = \frac{m_0^2 \frac{v^2}{c^2} c^4}{1 - \frac{v^2}{c^2}}$$

and by adding and subtracting a term it can be put in the form:

$$p^2c^2 = \frac{m_0^2 c^4 \left[\frac{v^2}{c^2} - 1\right]}{1 - \frac{v^2}{c^2}} + \frac{m_0^2 c^4}{1 - \frac{v^2}{c^2}} = -m_0^2 c^4 + (mc^2)^2$$

which may be rearranged to give the expression for energy:

$$E = \sqrt{p^2c^2 + (m_0 c^2)^2}$$

Note that the m with the zero subscript is the rest mass, and that m without a subscript is the effective relativistic mass.

$$E^2 = p^2c^2 + m_0^2 c^4$$

Let's make c = 1

$$E^2 = p^2 + m_0^2$$

$$m = \sqrt{E^2 - p^2}$$