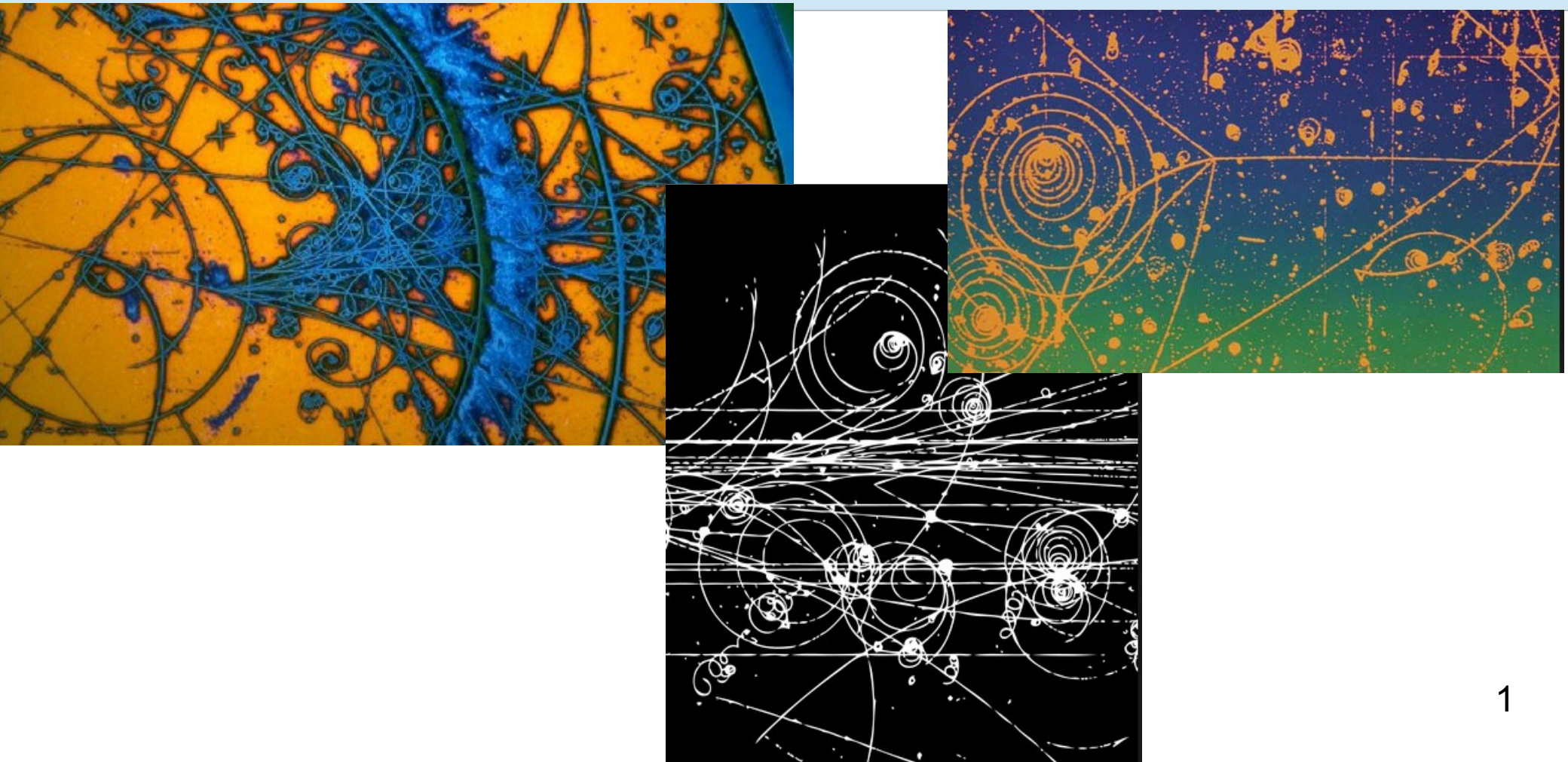


Passage of particles through matter



Types of particles and how they interact with matter

All charged particles leave a trail of ions as they pass through material.

Energetic electrons form an electromagnetic shower

Strongly-interacting particles (anything containing a quark) will create a hadronic shower

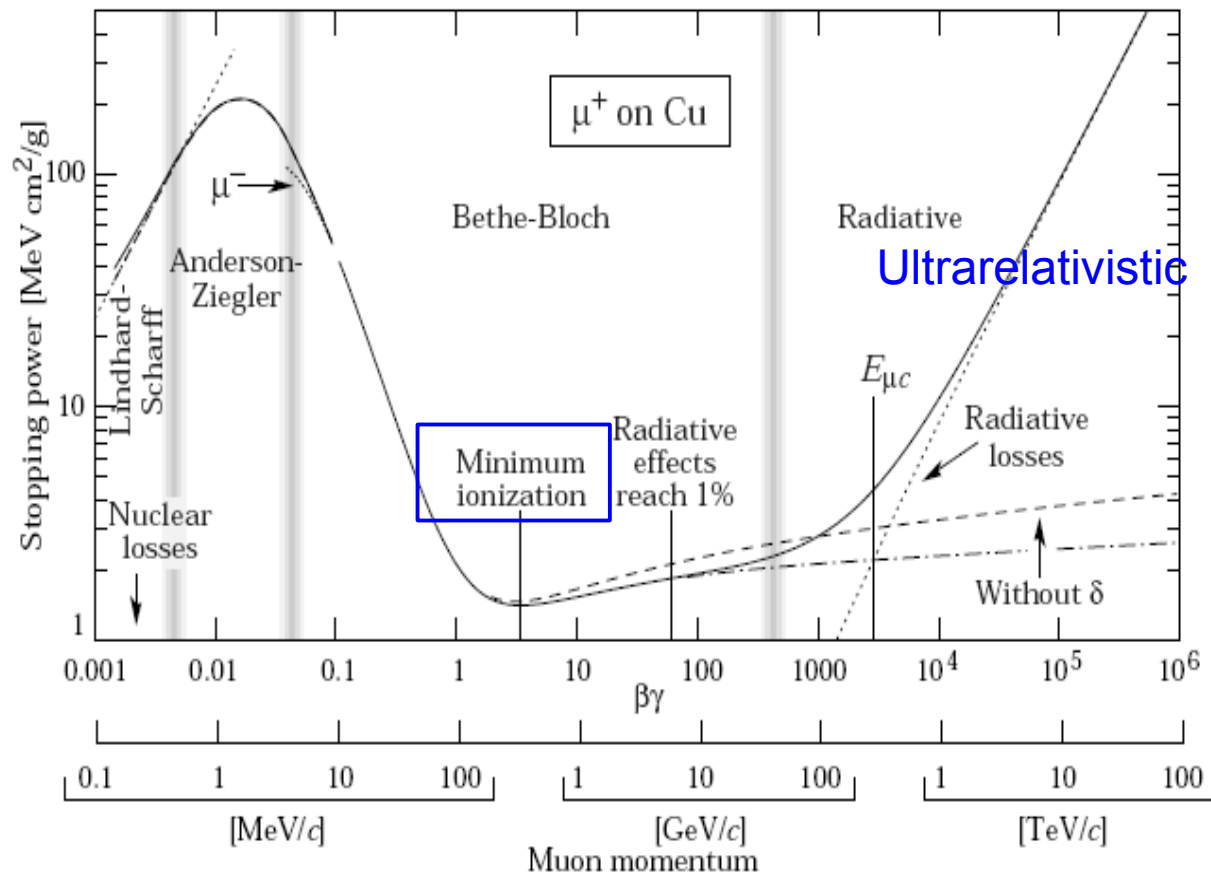
Neutral particles do not leave a trail of ions.

- Neutrons will make a hadronic shower

- Photons will create an electromagnetic shower

- Neutrinos will escape the detector without interacting...but we can detect them by the **missing energy!**

All charged particles lose energy through ionization, dE/dx

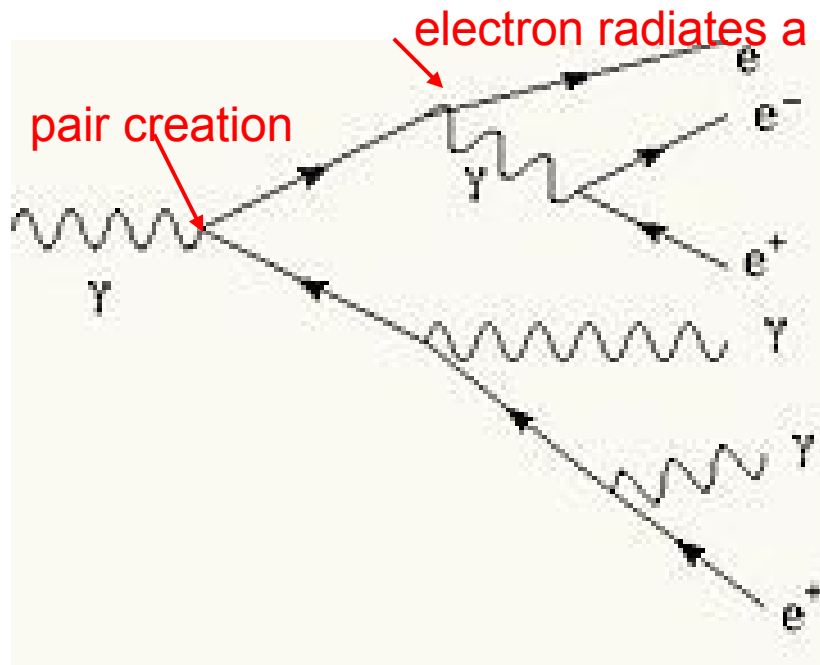


Bethe-Bloch equation (note units)

Homework problem: what is the $\beta\gamma$ of a 100MeV kinetic energy electron?

Of a 100 MeV muon?

Electromagnetic showers



Electrons and photons which are energetic enough make showers of electrons, photons, and positrons, called electromagnetic showers.

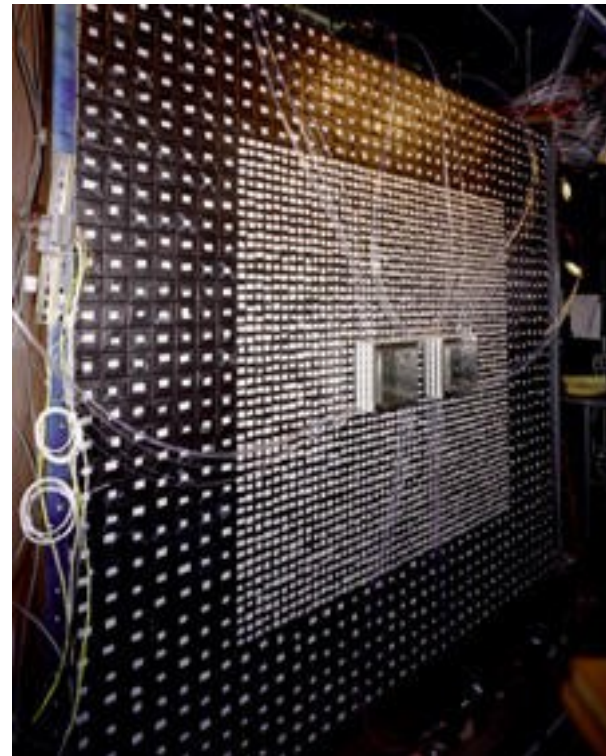
Question: what is the minimum energy a photon needs to pair produce?

To start an electromagnetic shower, you need about 0.5cm of lead.

A calorimeter is a device that measures the energy of a particle by making it shower and measuring the energy in the shower, usually by turning the energy into light.

Electromagnetic showers

To start an electromagnetic shower, you need material with a large atomic number, like lead, uranium, or tungsten. Here are some CsI crystals that were used in a Fermilab experiment called KTeV.

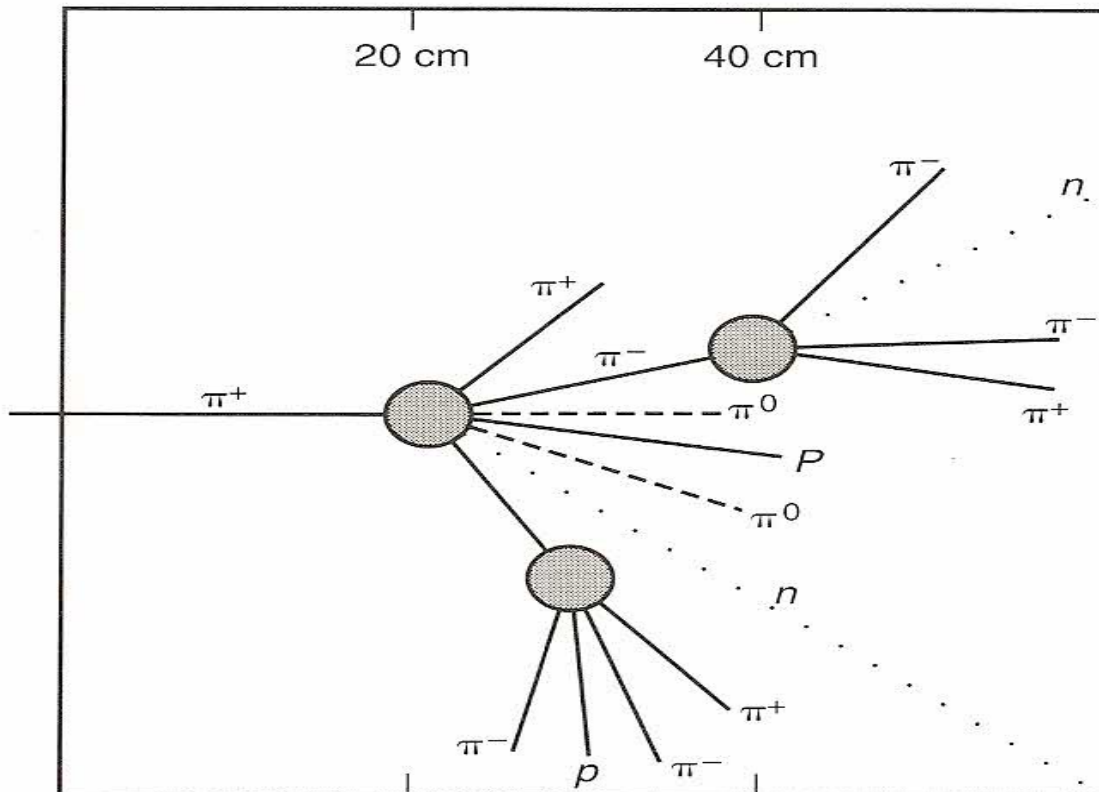


Cs I crystals for KTeV

Hadronic showers

Hadrons are strongly-interacting particles. All particles containing quarks are hadrons.

Hadronic showers are created when a hadron passes through enough material to make many interactions.



To start a hadronic shower, you need lots of material—17cm of lead for example.

We also use calorimeters to measure the energy of hadrons, but they are much larger than electromagnetic calorimeters.

The special case of muons

But muons are like heavy electrons, why don't they make a shower too?

The probability of radiating a photon goes as $1/M^2$ and the muon mass is 200 times the electron mass.

Muons “MIP”* (minimum ionize) through material, losing energy slowly to ionization. They are therefore **very penetrating** and can pass through meters of steel without interacting. They do not make hadronic showers at all, and they do not make electromagnetic showers unless they are extremely relativistic, because of their large mass.

* There is no noun that can't be verbed.

So the usual way to detect muons is to put up several meters of steel and see what comes through. Only the muons will get through!

Detect them all!

We want to detect ALL of these particles! It takes more than one type of detector to do that. A typical detector in a particle physics experiment will contain several subdetectors, as we move away from the interaction region.

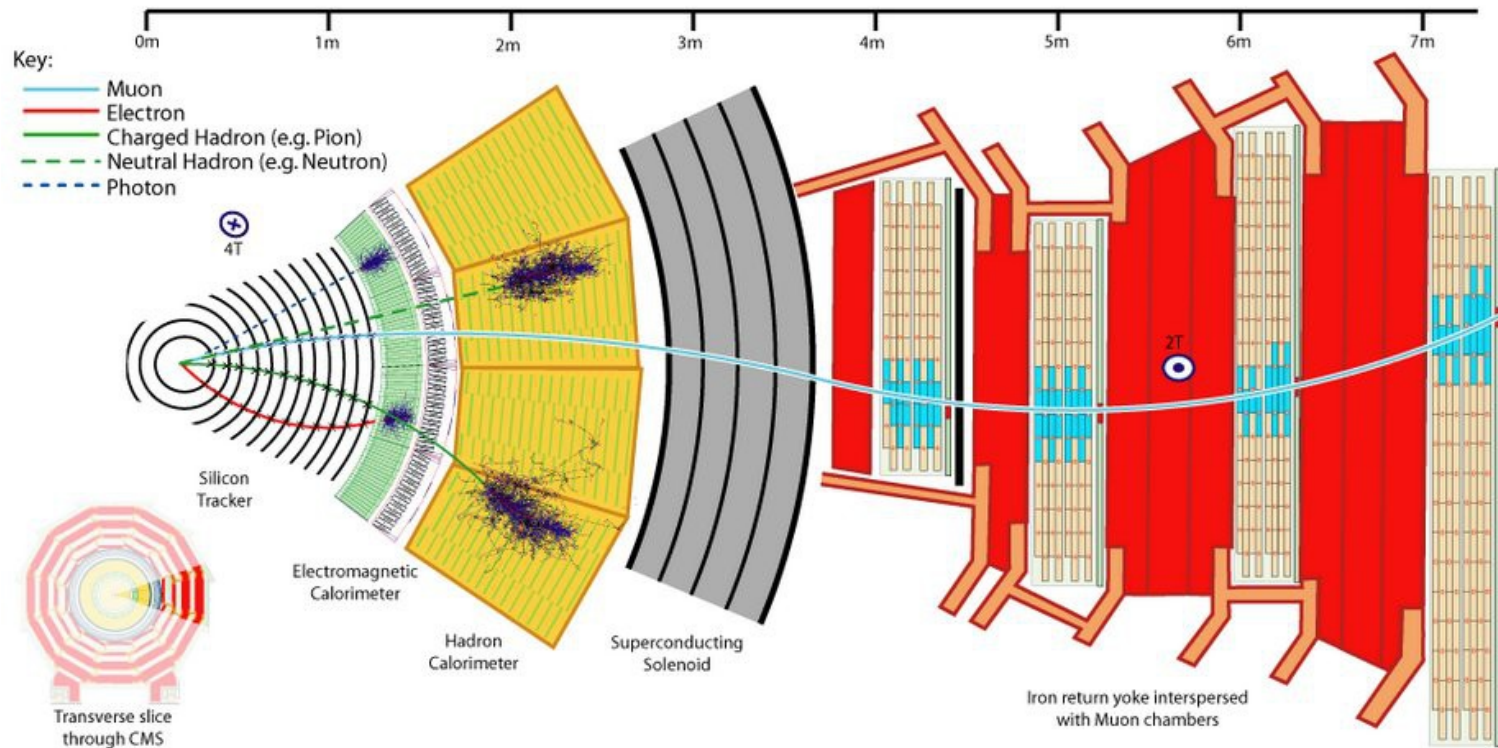
The tracker, which traces the path of charged particles. This detector sits in a large magnetic field, so the particles curve, and we can measure their momentum. This detector does NOT see neutral particles. We build a tracker to disturb the particle as little as possible.

Electromagnetic calorimeter causes electrons and photons to make electromagnetic showers, stopping them completely. However hadrons and muons pass through.

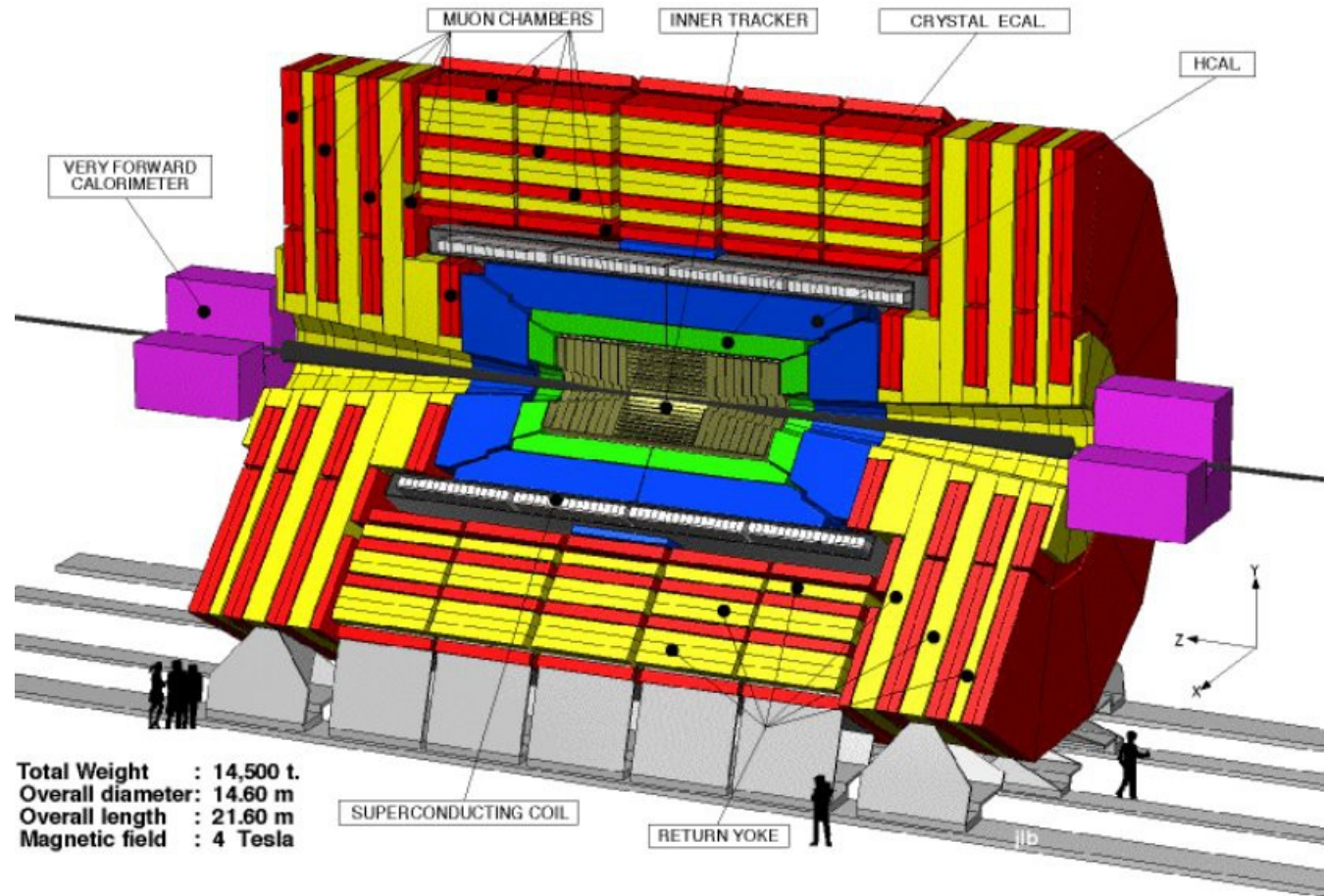
Hadronic calorimeter causes hadrons to make a shower, stopping them completely, but muons make it through.

Muon detectors sit behind a few meters of steel, so that only muons make it through.

A slice of the CMS detector

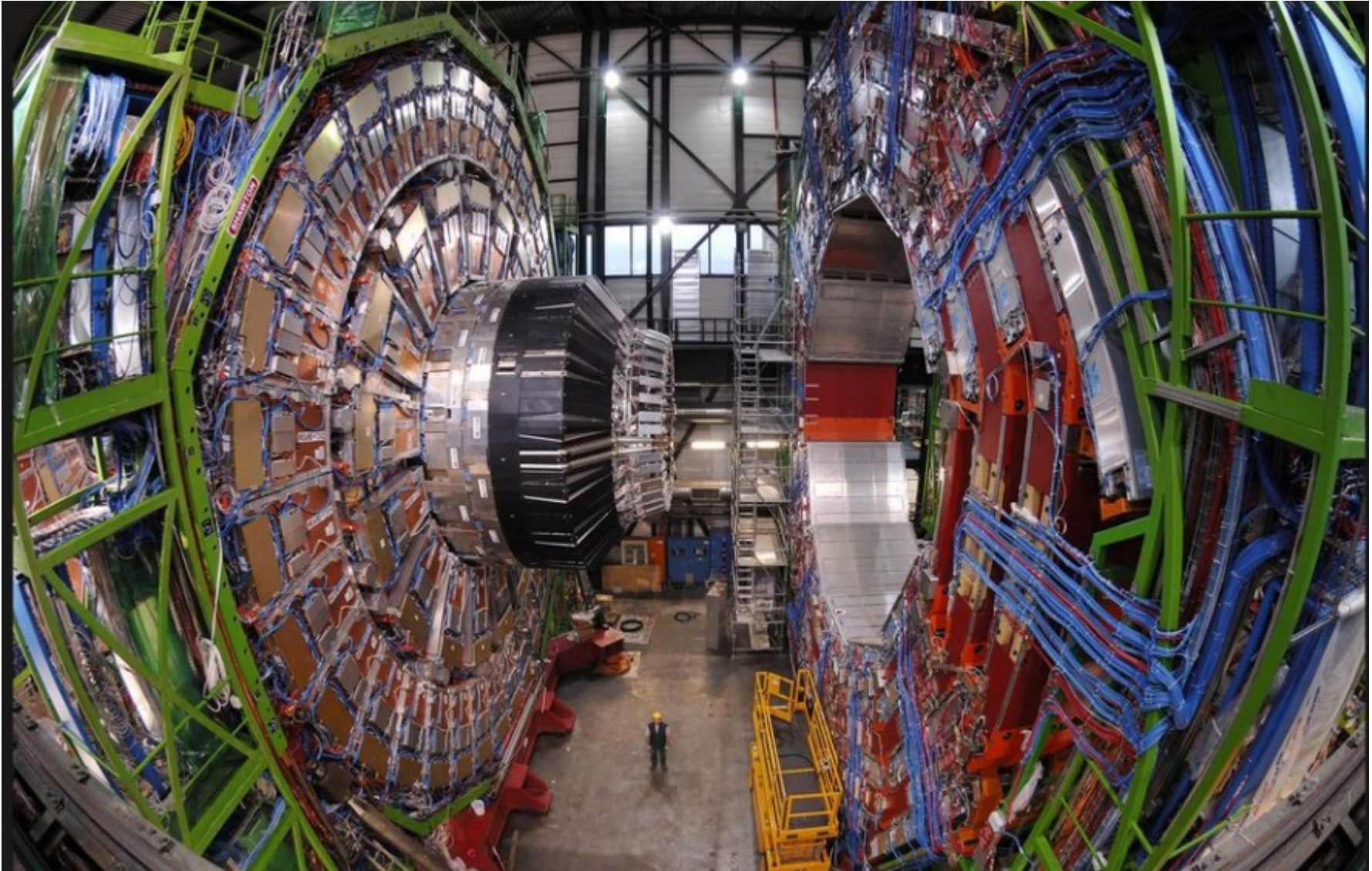


CMS detector



The behavior of particles as they pass through matter dictates what a detector must look like. The subdetectors, from the beam to the outside, are the tracker, EM calorimeter, hadronic calorimeter, steel, and muon detectors

CMS detector



How do we detect particles?

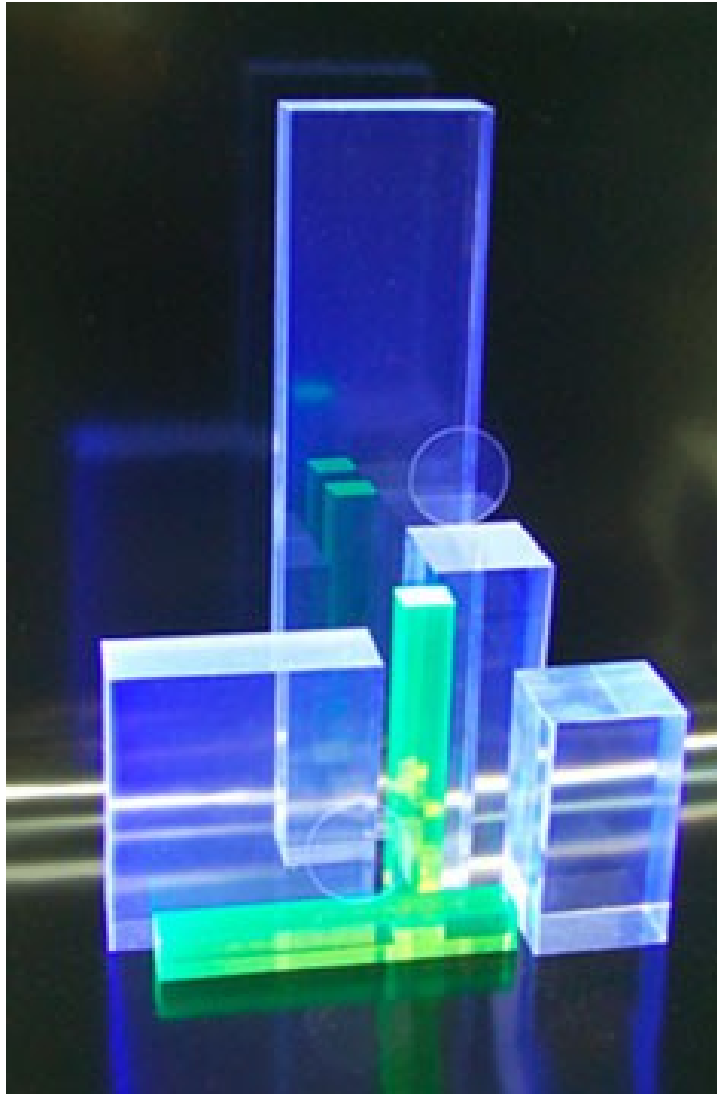
When energetic charged particles pass through matter, they leave a trail of ions. Most detectors work by seeing these ions one way or another.

Classes of detectors

- **Plastic scintillators—rough spatial resolution, precise timing.**
- **Tracking detectors--precise spatial resolution**
- **Calorimeters—measure the full particle energy, including neutrals.**

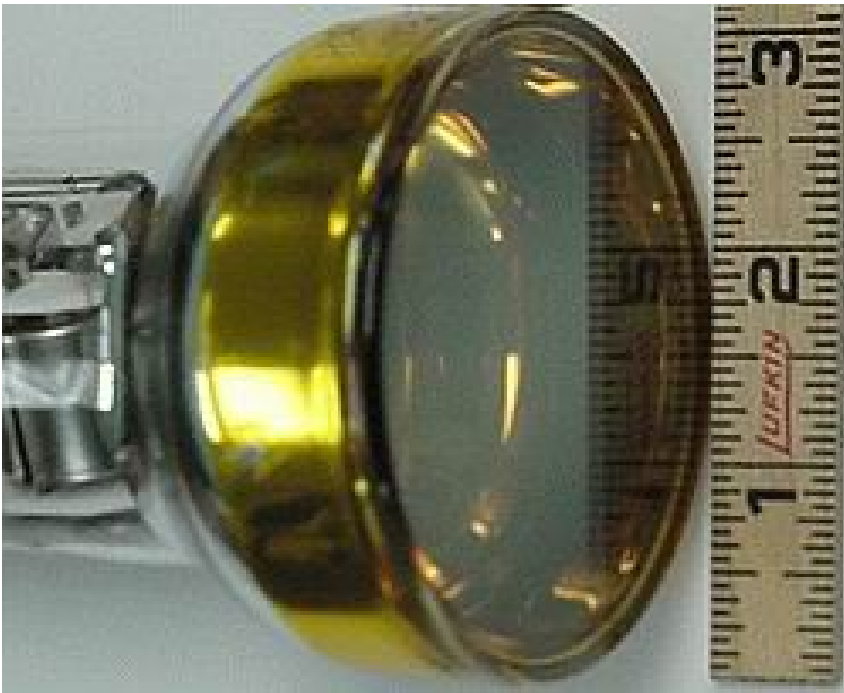
An experiment will usually contain all these types.

Plastic scintillators



The chemicals in the plastic give off light when charged particles pass through them.

Scintillation counters



The light is detected by devices called phototubes.

The combination of scintillator and phototube can achieve a timing resolution of less than a nanosecond.

Phototubes

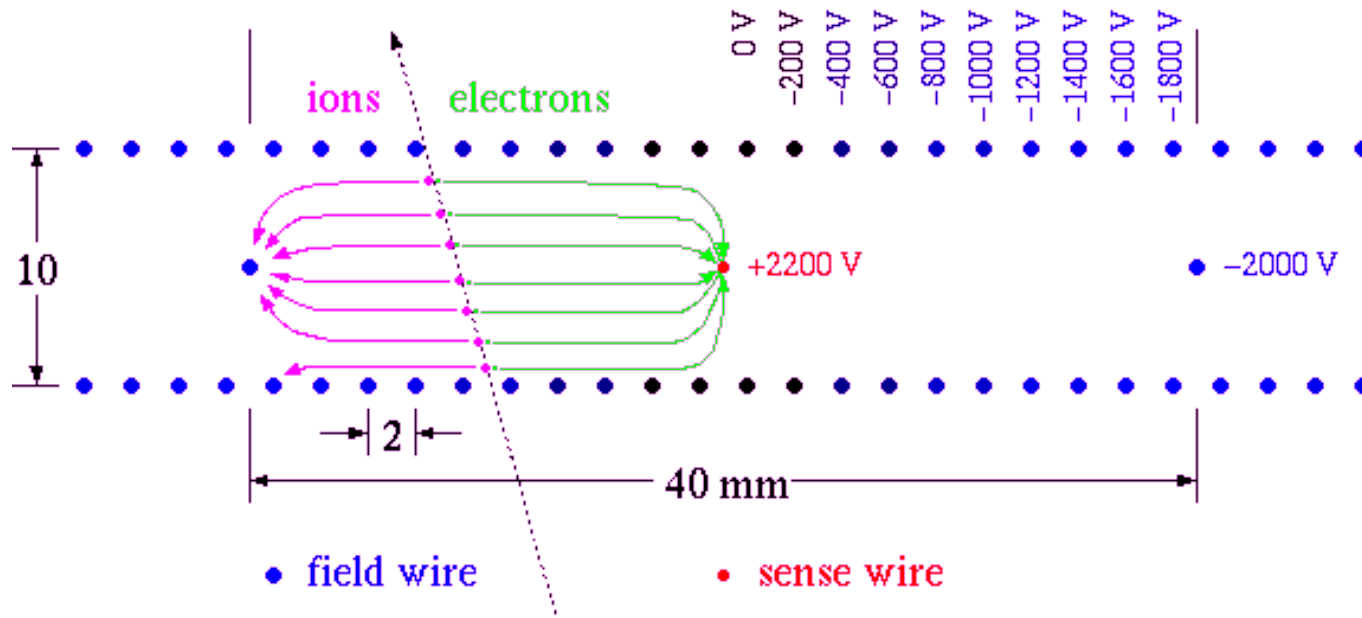


Phototubes are extremely sensitive light detectors used in many applications. They come in many sizes and shapes.

SuperKamiokanda phototubes

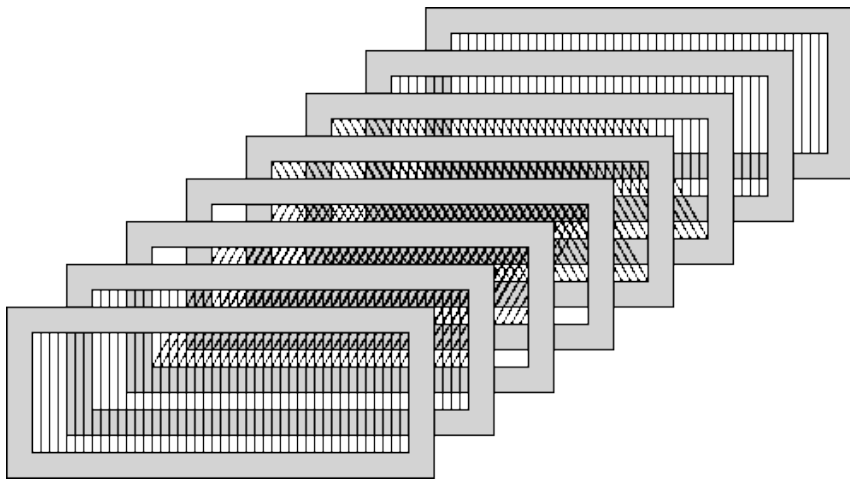
Tracking detectors

Many tracking detectors made of very fine wires can give spatial resolutions of order 100 microns.



Tracking detectors

Many layers can be placed one behind the other to trace out a particles path in space.



Wires are horizontal, vertical, and at angles in between.

Tracking detectors



In collider experiments, tracking detectors are usually cylindrical.

This shows a large tracking chamber being put inside the magnet at CDF at Fermilab.

Magnetic fields

Magnetic fields are used to measure a particle's momentum.

Nonrelativistically,

$$\mathbf{mv}^2/r = \mathbf{qvB} \quad (\text{cancel one power of } v)$$

$$\mathbf{mv}/r = \mathbf{p}/r = \mathbf{qB}$$

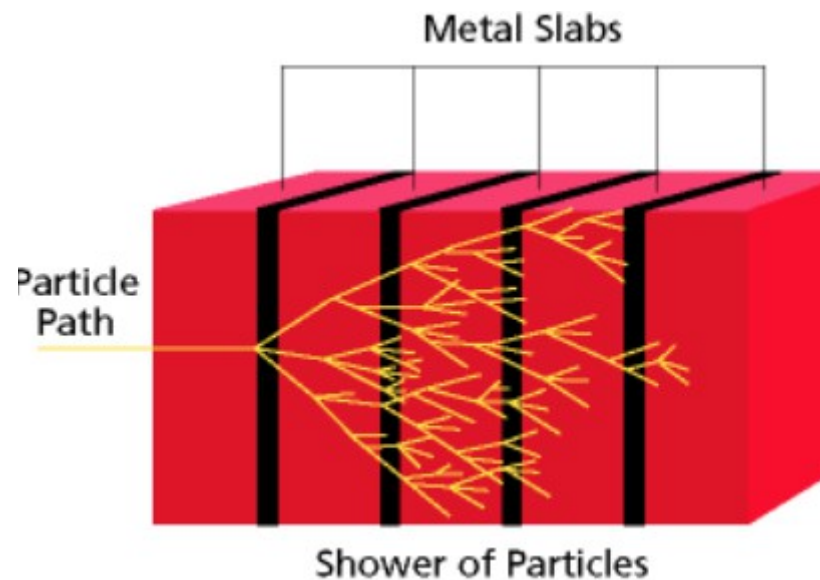
The correct relativistic expression uses the momentum.

Electromagnetic calorimeter



An electromagnetic calorimeter puts some sort of high atomic number material in the path of the particles. Electrons and photons form electromagnetic showers, deposit all their energy, and stop.

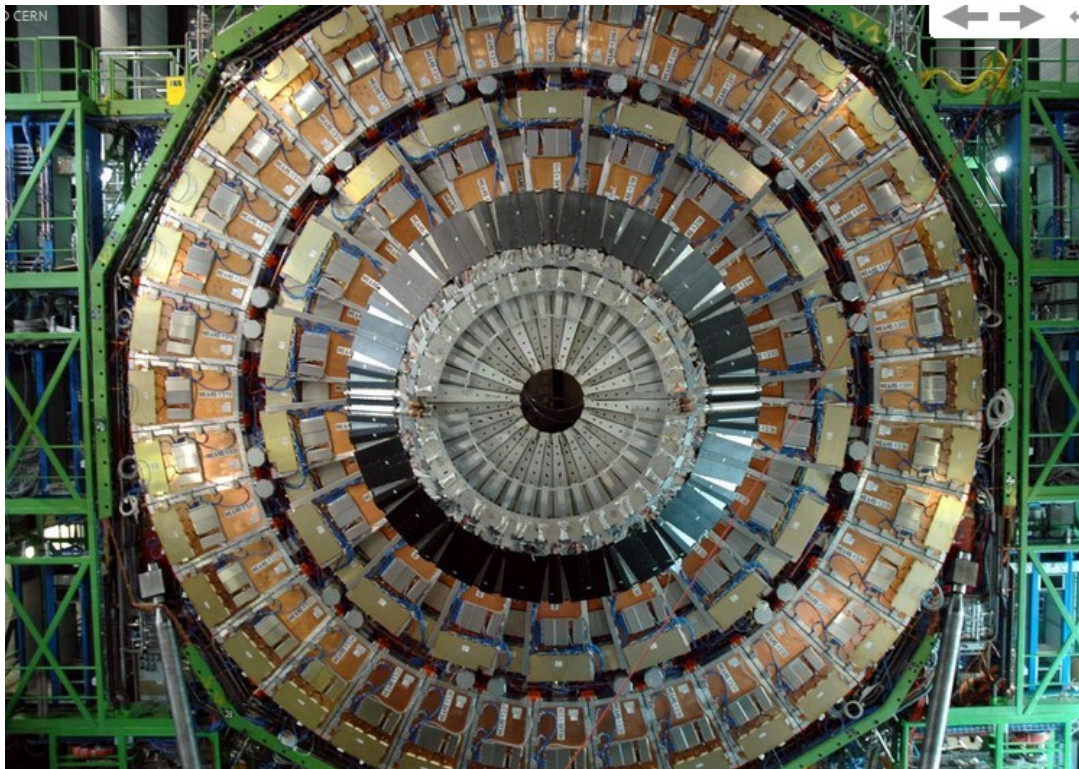
Hadronic calorimeter



You need a lot more material to make a hadronic shower, so hadronic calorimeters are much thicker. Between the metal slabs will be some detector such as scintillator. The CMS calorimeter uses stainless steel and copper for the absorber and scintillator to detect the particles created.

Muon detectors

Muon detectors are some sort of tracking detectors, often wire chambers or scintillator, put outside a few meters of steel. Only muons can make it through the steel, so any particles that are seen in those detectors must be muons.



**CMS endcap
muon chambers.**

Summary of passage of particles through material

