Today we discuss other ways in which the LHC detectors observe the Higgs Boson. Because the decay of a particle is independent of the way that it is produced, the Higgs bosons we discuss in this lecture are primarily produced via the fusion of top quarks as discussed in Lecture 3. The figure on the right shows the relative probabilities for different decay modes of the Higgs. The size of each slice of the pie is determined by how strongly a particle couples to the Higgs (its mass) and how much energy is available for the decay. In cases where the sum of the decay particles’ mass is larger than the Higgs mass then one of the decay particles has to be off its mass shell. This means that the particle has a mass that is smaller than the mass that we typically measure. This is possible, via the quirks of quantum mechanics, but happens rarely, which reduces the rate of Higgs decays to very massive particles.

The photon decay mode is tiny (0.3%) because it has no mass, but it has such an obvious signature in the LHC detectors that we started with it. Another such “clean” channel are the decays to a pair Z bosons when Z bosons themselves decay to electrons and muons. The Higgs decays to Z bosons 3% of the time, and Z bosons decay to electrons or muons 3% of the time, so to have both Z bosons in a Higgs decay end up as electrons or muons is rare (0.1%). It only happens in .03% of Higgs decays. However, there are very few other processes which produce four electrons and muons in the LHC detectors so these events are easy to find.

So, how do we find electrons and muons? Because of the electromagnetic showers discussed in lecture 3, electrons look very similar to photons in the calorimeters, so we won’t discuss that further. However, electrons are charged particles so we can use that fact to observe them before they start showering in the calorimeters, allowing us to distinguish them from photons. Muons are also charged particles, but they do not lose significant energy to electromagnetic showers, so we observe them by looking for charged particles outside of the calorimeters.
There are many ways to register the presence of a charged particle without significantly altering its energy. Detectors which do this are typically called **tracking detectors**. A wide variety of technologies are used for these detectors. Today we discuss two of the most common at the LHC, **silicon** detectors and **gas** detectors. Silicon is a **semi-conductor**, therefore when it is subjected to an electric field, only electrons with certain energies travel freely through the material. In normal conductors, such as copper, electrons of any energy travel freely; insulators do not have any free electrons. When charged particles pass through a semiconductor they can transfer enough energy to some of the electrons to allow them to move freely. We then measure the number of liberated electrons and we know a charged particle has passed through the material.

In gas detectors liberated electrons are also used as the signature of a charged particle. Tubes or chambers are filled with inert gases. When a charged particle passes through the gas, it knocks electrons out of the atoms which are collected in many ways. Often, wires held at a high voltage are embedded in the tubes or chambers and attract the electrons. Or, the walls of the chamber are patterned with electrodes which collect the freed charges.

Both silicon and gaseous detectors are layered to make multiple measurements of a particle, allowing its trajectory to be reconstructed. These detectors are typically immersed in a magnetic field so that we can deduce the particle’s momentum from the curvature of its trajectory. Silicon detectors reside close to the interaction point because they can be made with very fine granularity, which is needed in dense environments. Because they are inexpensive and can affordably cover a large surface area, gas detectors are further away and are often used in muon trackers.

Electrons are found by combining information from the inner tracking detectors with the calorimeters. Muons are the only charged particles which can make it through the calorimeters without showering so by putting tracking detectors outside the calorimeters we identify muons. When we find an event with 4 electrons, 4 muons, or 2 muons and 2 electrons we combine their energies and trajectories to see if they could have come from a Higgs boson. That will be discussed in the next lecture!