MARKUS KLUTE: Welcome back to 8.701. So now the theory about Higgs boson is quite interesting. And we have seen that it's able to produce masses of boson and of fermions. But as Feynman said, a theory is only as good as the experiment. And so we have to actually find Higgs boson and measure their properties and see whether or not their properties are consistent with the standard model.

And so the first question we have to ask is how Higgs boson is actually produced and how they might decay. So this little video is just talking about this in very simple terms.

So we are able to produce Higgs boson at proton-proton machines, at proton-proton colliders, because they are able to bring collisions or produce collisions which allow to have energies of a mass scale consistent with the Higgs boson. We already know now that the Higgs boson has a mass of 125 GeV. So the collisions have to have enough energy to produce this particle.

We're using protons to do this because protons can be accelerated easier than electrons, for example, to those energies. But protons themselves are, as we have seen, objects which consist of quarks and gluons. So how do gluons now produce Higgs bosons? And this is shown in this Feynman diagram here where you have two gluons from two colliding protons.

And they are able via this loop diagram, triangle diagram, including the top quark-- the top quark goes around here-- to cause an excitation in the vacuum, which is the Higgs boson. They couple to the vacuum producing the Higgs boson.

And then instantaneously, the Higgs boson decays. And it can do this in various ways. And we look at this on the next slide. And in this example, it decays via a similar triangle loop into a W. And then the W is electrically charged and can radiate a pair of photons.

So while the gluons and the photons are massless, we are able to produce Higgs bosons via the collisions of two gluons and observe it via decay into photons. This is quite spectacular.

In more general ways, it's not just one mechanism to produce Higgs bosons, but there's various. And the leading ones are shown here. We have just looked at this first one, which is called gluon fusion channel, so two gluons fuse together to a Higgs boson.

There's this one here, the second one, which is called Vector Boson Fusion, BBF, where we have the quarks radiate to vector bosons. This is either the Z boson or the W boson. And then those couple to the Higgs field and produce the Higgs boson. We can also have associated production where we have two quarks via, again, a Z boson or a W boson radiating then a Z boson or a W boson and generating a Higgs.

And then a very exciting one is the last one here where the Higgs boson is produced in association with two top quarks. Remember, the top quark here has a mass of 175 GeV. The mass of the Higgs boson is 125 GeV. And so we have two of those. So the scale of this event is in the order of 500 GeV.

This plot here shows the production cross-section as functional center of mass energy. Now the Large Hadron Collider, the LHC, operates currently at 13 TeV. So the cross-section we want to look at those.

So you see that the leading cross-section, which is in the order of tens of picobarn, is the one where we have gluon fusion. On the order of magnitude less is the one with vector boson fusion. And then we have associated production. And then the last one is the one where we have Higgs boson produced in association with top quarks.

Because the mass scale is much higher, the cross-section for TD Higgs is lower. If you were to increase the center of mass energy of the LHC, you see this rapid increase in cross-sections just because there's more phase base available for this production. The coupling here and the coupling here is the same.

Then the Higgs boson, as I said, decays. And we have already discussed Higgs branching ratios, or branching ratios in general. And since the coupling of the Higgs boson to fermions is proportional to the mass of the fermions, you see the dominant decay is the one into Higgs to bb-bar. And then you can find lower decays to the taus, the [INAUDIBLE], and to muons here.

You also have to into the vector bosons, W-W, and Z-Z. So similar triangle diagrams, you have decays into glu-glu, and then to photons as well. So we have already measured the Higgs boson at 125 GeV. And so those are the branching ratios as predicted in the standard model.