[SQUEAKING]

[RUSTLING]

[CLICKING]

**MARKUS KLUTE:** Welcome back to 8.701. So in this lecture, we open a new chapter of weak interaction. So we are one by one adding together the components we need in order to describe all elementary particles and their interactions. And I'll be adding the third form of interaction. After the QED and QCD, we enter into the discussion of the weak interaction.

So let's have a look at the standard model. So we discussed gluons and QCD. And we saw that gluons couple to themselves and also to all quarks. Because they carry a charge under the-- on the QCD, a color charge. We have also discussed the photon, and seen that the photon, they do not couple to themselves, but they couple to all charged elementary particles. Those are the meta particles, the fermions. The photon also couples to the W boson. We call it the electrical charge.

So now what we want to do in this next chapter. We want to fully understand the W and the Z boson. And we will see that they couple to all meta particles. And we'll also discuss how they might couple to themselves, or the Z boson couples to the W boson.

Well, that's the story of this entire chapter, and we'll take it one by one. As an introduction, we start with the Feynman Rules. So having the Feynman Rules in place, and the cookbooks, the recipe, in order to calculate decays and scattering processes. That is all we need in order to get moving. You can, for example, look at this vertex here, of this component of the Feynman diagram. And what we need to analyze this is the propagator for the W and Z boson, and the vertex factor.

This vertex factor now looks a little bit more complicated than for QED and QCD, because the W boson and the Z boson, they carry mass. So we have some additional factors. q squared minus M square. And this q squared over M squared term as well.

One interesting fact about this vertex factor is what happens now, is q squared is much, much smaller than M squared. We have to get rid of those components here, and we find a vertex factor which looks similar to the one we have in QED. However, that's not one over q squared term, but 1 over M squared term, which is constant.

So we would see that we can describe this in the context of the Fermi theory, which is a lower energy approximation of the full theory of heat conduction. It's kind of an interesting concept, and it extends to the entire understanding of the standard model.

It might be that our standard model, you know, that we have all the packages together, describes the lower energy approximation of a more complicated-- more holistic theory, which we then can discuss under the concept of a grand unified theory. Maybe there's a symmetry group which is embedding the symmetry groups we need for QED, QCD, and the weak interaction. But that's a side remark. So we will look at the Fermi Theory a little bit more later.

The vertex factor itself, describing the vertex here. It's given here. For the W boson, and also for the Z boson. And it looks a little bit more complicated than the vertex factors we have seen so far. What you notice that there is the parameter, which is associated to the strength of the interaction.

And the gamma matrix. But there's also this term here, which has two components. There's the one, and the gamma 5 matrix. We have talked about gamma 5 matrix already. And we can later identify those as individual currents are coupling to vector current and an [INAUDIBLE] current.

So this looks even more complicated now for the Z boson, because here we have not just numbers of one, but an additional factor. This factor cV is a vector coupling, and it's specific for each fermion. So each fermion has one of those constants. And the second part of the package or set of constants, for the axial current. You have a second parameter here, which is the strength of the coupling of the Z boson.

So at this point, you just take this axial, and you can do all our calculation. On our next slide, I'm going to explain to you what the corresponding numbers and what d values are for those parameters cV and cA. Later, we will see how it comes to this more complicated structure, and why there is a vector, and why there is an actual axial current in the weak interaction. But for now, we just take this for granted, and we just take this as a recipe.

So now for the neutral. So we've just have seen that this is the vertex factor. And here, for all fermions, we list what these values are for cV and cA. What you can see is for the neutrinos, the factor is one half, both for cV and for cA. And for the charge leptons and quarks, there is an even more complicated term here, which includes a new parameter. Sine squared theta w. The value of this is 28 degrees. Sine squared theta w is 0.231.

As a little bit of a preview here already, the fact that there is this new parameter and an angle involved leads to, or can be explained later, by the fact that the weak interaction is actually a result of a mixing between an original weak interaction, and QED. So there's a mixed thing going on.

In other words, the Z boson itself is a mixture between the thing which couples to the weak part of the particle, and the part, which couples to the electrically charged part of the particle. When you see that, that's why there is a simple factor for the neutrinos who are electrically neutral, and a more complicated term here for the electrically charged particle. And you see that this is the electric charge here. Or two times the electric charge of the particles.

But for now, those are all just constants and recipes to be used. One additional word on the history of the neutral charge of the neutral weak current is given here. So in the '60s and '70s, the standard model was slowly developed. A little bit more slowly than we do in this class here. And there was-- the hypothesis is that there have to be something like a neutral current in there. But it has never been observed in nature.

And so this bubble chamber, specifically the one Gargamelle at CERN, one was able to actually see those, see virtual and really see, those interactions for the first time. And the first pictures that have been taken in the 1970s, 1973. And this picture here illustrates-- I will expand it in a second-- illustrates the interaction of a neutrino coming into the bubble chamber, making an interaction with an electron, and then scattering off, kicking off the electron.

So what you see here is this incoming-- this is an anti-neutrino kicking off an electron. See the electron here. The neutrino goes off undetected. It just disappears. You see here, the electron. And then there's also two protons. One proton here.

Let's use a different color. And one photon here. Causing electron positron pair, and the second photon here doing the very same thing. You can see those particles here. See here and then going on here as well.

So this is a bubble chamber picture. We'll talk about bubble chambers very briefly later in the lecture as well. But they're very extremely important and useful tools in order to illustrate-- to visualize and measure particle interaction. All right. So much to the introduction, and we'll continue now with the next lecture on talking about this mixture, this electroweak mixture [INAUDIBLE]