MARKUS KLUTE: Welcome back to 8.701. In this chapter, we will talk about neutrinos. And we'll start the discussion with a relatively simple introduction. How does a neutrino look in the standard model, and how does it interact?

We have discussed the neutrino already quite a bit. So this is more or less a summary. In the standard model, the neutrino is massless. It's a massless particle. And it interacts with a weak direction. So it interacts with w bosons and with z bosons. And specifically, it does not interact with photons of gluons.

If we look at the Lagrangian or try to write down the current, we find that there is a charged current via the w. And there is a neutral current, we have the z boson. It's quite interesting to think about those two currents a little bit more.

So in case of a charged current, for example, I have an incoming neutrino, we can determine the flavor, the kind of neutrino we have. We are detecting the flavor of the lepton. So if, for example, identify an electron in this interaction in the interaction, the initial neutrino was an electron neutrino. While for the neutral current, when we have some sort of interaction happening, we cannot identify directly the neutrino. Hence, we cannot find the flavor of the neutrino. You can just measure the sum of all flavors of neutrinos in the neutral current.

On that story, neutrinos have three flavors. They come in electron flavor, muon favor, or tau flavor. Neutrinos are left-handed. Anti-neutrinos are right-handed. So that's the story. That's how neutrinos are characterized in the standard model.

In the standard model, in the framework we set up, we can calculate cross-sections, scattering cross-sections. And here, we are looking in the neutrino nuclei scattering. Again, we can split this up in the charged current and neutral current discussion. But they go very much in parallel.

So we have elastic scattering. Or in the case of the charged current, we talk about quasi-elastic scattering. Then we have an incoming neutrino, let's say a muon neutrino, hitting a neutron, producing a muon and a proton. It's called quasi-elastic, because we do not break up the target, but we change its kind. So we change from a neutron to a proton, in this case. While, for the elastic scattering, the neutron just stays intact.

We can also have nuclear resonance production, where we hits the nuclei. And then inside the nuclei, we could use a [INAUDIBLE], like a neutral or a charged [? pion. ?] And also, that's possible in the neutral current exchange.

And then we have deep-inelastic scattering, where we hit a nuclei or nucleon that hard, that we'd start breaking it up. And in this case, we scatter off the quark, and we produce a new quark in the charged current interaction in the same quark in the neutral current interaction.

So this is no different from the stories we had before. The intriguing part about studying neutrino scattering is that we do know that we have weak interactions being-- we use a dominant force of being the process. While, if we use photons to interact, or we have electrons being [INAUDIBLE], then we can have a mixture of weak and electromagnetic interaction.

Another important takeaway from this slide is that, when we calculate cross-section, we find that a linear increase in the cross-section of the function of the energy. So while cross-sections for neutrinos are small, at higher energy source cross-sections scale linearly. As we can discuss this for neutrino scattering with nuclei and nucleons, we can also look at neutrino scattering with electrons directly. There's a lot of electrons in the metal around us.

And the neutrino [INAUDIBLE] with this metal that can interact with electrons, too. And they can live in the charged current interaction of muon in an electron neutrino and in a neutral current interaction in electron in the [INAUDIBLE]. Also, here, you see cross-section, total cross-section scaled with [INAUDIBLE] energy. Good. It's the first introduction to neutrino physics. We'll go into more detail in the following presentations.