MARKUS KLUTE: Welcome back to 8.701. We have seen in the previous video how neutrinos can acquire mass. When they have mask, ["mass"?] their weak eigenstate is not equal to their mass eigenstate. So we observe the same mixing as we have seen in the quark sector.

So let's review this a little bit. So just starting from two neutrino generations, we can write the flavoring states. We are mixing of mass eigenstate. If we do this, it's a simple matrix. You find that there is one angle used for the rotation of the mass eigenstate into the flavor eigenstate.

All right. So we can add some time to 0, write our neutrino or our muon neutrino as a combination of the 1 and 2 mass eigenstates. If we then have this neutrino evolve as time, we see that the relative contribution of the 1 and 2 mass eigenstate actually changes.

So if we do that, so obviously you find some time evolution. If we then ask ourselves, what is the probability that we start from a muon neutrino that we actually find in an interaction electron neutrinos. Through this mixing of mass eigenstates, we can calculate this probability just by squaring the amplitudes. If you do this, you just use this part here. We find that there is a cosine E2 minus E1 term.

All right. Good. So let's analyze this a little bit further. We know that the masses need to be small. So one thing we can also do here is do a Taylor expansion of our energy and then just revise the term. If you then analyze it some more, you find that the oscillation probability simply depends on the mass difference squared, the length of distance the neutrino had time from 0 to oscillate, and the energy of the neutrino.

So this is fantastic, because now by studying the probability for a neutrino to change its flavor, we can infer the mass differences of two states. This is fantastic. I should add here that in this case, in this formula, the length is given in meters, the energy is given-- unit of the energy MeV and the mass difference is in eV, otherwise the equation doesn't make sense.

So again, we have seen, if you start from two neutrino kind of model, two neutrino flavor model, that the experimental parameters of interest here are the length of distance from the neutrino source to the detector on the place where we generate a specific neutrino of a specific flavor, to where we actually observe the flavor of the neutrino and the energy of the neutrino.

And then, the appearance or disappearance of a muon neutrino, for example, if we start from a beam of muon neutrinos, is a function of the length of the source. And this is shown here for neutrinos of a specific energy.

So you can observe or can try to measure the disappearance of muon neutrinos or you can try to find the appearance of electron neutrinos in the specific two-neutrino model. All right. So all we find later is that we want to look for disappearance and appearance of neutrinos of specific flavors in order to probe mass differences.

Instead of doing this for two generations, you already know how to do this in three generations, you can find that the unitary matrix has three angles, three rotations and one complex phase. And this looks very much the same here as in the quark sector. The big difference is that the values of those parameters are quite different.

For the quarks, we have seen it's dominated by the diagonal. And then we have seen, for example, in the Wolfenstein parameterization that we can do an expansion of the matrix and see terms which are all of this lambda, which would all point to two and number square and number acute.

Here, on the leptons sector, the situation seems to be quite different. We have a later lecture where we look at the extra parameters and the numerical values. But what you see here is that it's more like democracy between the individual values.

Question is, do we have sensitivity to the complex phase? We can only have that sensitivity if the value of this matrix element is non-zero. And this has been observed already. So that's good news in order to allow further neutrino studies.

So in general, you can write the oscillation from one flavor to another flavor state using this rotation of matrices we have seen, and with that measure the individual components of the matrix.