MARKUS KLUTE: Welcome back to 8.701. So this is our last video in the chapter on neutrino physics. And we'll talk about mass scales and the nature of the neutrino particle very briefly.

When we think about how we can measure the neutrino masses, there's a number of methods which come to mind. The first one is to just look out into the universe and try to understand how much matter in total could come from as a source of neutrinos. And one has to make assumptions about the model, the cosmological models at hand.

But if I accept those potential biases or model dependencies, one finds that there's a potential reach of this kind of measurements of 20 to 50 MeV, millielectron volts. And the current best limits are in the order of 0.1 to 1 electron volt.

A second source, and I'll talk more about this later, is the study of neutrinoless beta decay-- double beta decays. Here, the current best limits are on the order of 0.2 to 0.4 electron volts. And there's a chance to reach 20 to 50 millielectron volts.

This kind of measurement will also answer the question whether or not the neutrino is a direct particle or a Majorana particle as we discussed in earlier lectures. And then there is the more classical approach of measuring the mass of an neutrino from the end point spectrum of beta decays. And so here the current best limit is from the Kartrin experiment. And I talk about it in the next slide.

And it's in the order of one electron volt. And there's a potential reach to go down to 40 millielectron volt. So currently the range of limits is in the order of 1 electron volt or a bit better, and when we'll be able to go down to limits in the order of 20 to 50 millielectron volts.

So here is a cartoon of how those measurements are being conducted. One starts with tritium. And it uses beta decay. And this lecture overall is a good first entry into the nuclear physics program where we discuss beta decays and other nuclear decays in more detail.

What we find here is that you find an electron and the neutrino-- antineutrino in this case-- being emitted. And so the name of the game is now to measure the electron energy as precisely as possible, and then find a sensitivity off the neutrino mass in the end point spectrum. And those small differences here in the end point spectrum then that leads to understanding of the mass of the neutrino because the total energy in the collision needs to be preserved. And so the entire story here is about how precisely can we measure the energy of the electron in order to infer the neutrino mass in that.

And so the latest results came out last year from the Kartrin experiment and shows that the result is consistent with a neutrino mass of 0, and that we can set an upper limit at 90% confidence level. That electron neutrino is of mass of 1.1 electron volt. Just as a reminder, we measure the mass of the electron neutrino in this decay, which is the sum of the individual components, mass eigenstate, which make up the electron neutrino.

To just have historical context in this discussion here, we find that this latest result is an improvement of the order of factor of 2 compared to previous result by other experiments, which had a very similar job to measure the electron energy in beta decays, in the end point spectrum of beta decays.

There's a new approach, which has been proposed by Joe Formaggio here from MIT, which changes the way the electron energy is being measured. So the idea is to have the decay happen in magnetic fields, and use the cyclotron radiation of single electrons.

So the advantage here is that one doesn't have to move the electrons somehow into a spectrometer, but can immediately measure the energy of the electron. And the measurement of the energy then turns into a measurement of the frequency and basically measures the cyclotron frequency of the electron circling around in a magnetic field.

And so it turns out that one moves the measurement of the energy of the electron into a measurement of a frequency. And thus frequency can be measured with very, very high precision. So there's some hope that this kind of measurement lead to very, very precise results of the energy of the electron and with that the mass of the neutrino.

So the last slide here is now how can we figure out whether or not the neutrino has Dirac or Majorana nature. And this can be done, or the high sensitivity comes from so-called neutrinoless double beta decays.

So one starts with nuclear decays where two electrons are emitted, but no neutrino. And so this requires that in this process there's a transition which includes the neutrino where the neutrino has to be its own antiparticle. And that just means that the neutrino is of Majorana nature.

This is being done by measuring, again, the energy spectrum. You typically have all kinds of background contributions, but also backgrounds from double beta decays with two neutrinos. So you see this spectrum here.

And then you look at the end point of this part here and find that there is this peak, a precise sharp peak of the energies of the two electrons. The issue is that forecasting where this peak is requires proper knowledge of the dynamics inside the nuclei here. And those measurements are being conducted. There's many of them conducted in various nuclear transitions or decays. And they haven't yielded a positive result yet. Research is still going on on this end.