MARKUS KLUTE: Hello. So in the last video, we looked at ranges of forces. So we already saw one aspect, and wanted to learn about what kind of interaction happens when you study a specific force. You learn about the force carrier from noting the range in which forces interact.

In this class, we talk about decays. But in more general terms, when we want to measure properties of forces, we have basically three concepts at hand which can be experimentally determined. The first one is masses of bound states. | you might remember from atomic physics that you learn a lot about electromagnetic interaction by studying, for example, the hydrogen atom, where you have an electron circling around the program, and you can study in detail aspects of the electromagnetic interaction.

The second aspect is decay rates of unstable particles, or the width of an unstable particle. So in quantum mechanics, the lifetime of the particle is related to the width. And so that's what we're going to discuss in this video.

And then lastly, we can look at the reaction rates expressed as cross sections. So that's the topic of the next video after this. Let's talk about decays.

So we can define this new symbol, the decay rate lambda, and s as a function of time, probability that a particle will survive at least until some time t. We can now discuss this, and say, the probability at some time t relates to the probability at some time t plus delta t by the likelihood 1 minus the decay rate times the time interval, delta t.

And so from this, we find that the change of the probability for the particle to survive is proportional to that probability and decay rate. So now if we integrate this, we find that the log of this probability is equal to some constant times lambda decay rate times time. So now, if you simply assume that the particle existed at the initial time t, we said we set k equal to 0.

We find this very famous exponential decay law, e to the power of minus lambda t. And this is shown here in this picture as this exponential. So far, so good.

We can now define and look at this distribution a little bit more. We can, for example, look at the average time for that a particle lives, because the average time tau is simply given by the integral from 0 to infinity. So we basically integrate over this distribution to get the average time for the particle. And that's equal to 1 over the decay rate, 1 over lambda. You can do the algebra, yourself, in fact, to follow this.

So if you now express this probability for the particle to survive until some time t through the lifetime, you find this is equal to e to the minus t over the lifetime of the particle. So you might not want to look at one particle, but a sum of particles and look, at the time dependence of the number of particles which survived. Because it's equal to the number of particles as a function of time is equal to the initial number of particles times the probability that any given particle survives. And that's, again, given by this exponential.

In nuclear physics, one often talks about the half life, half life time of the particle or of [INAUDIBLE]. And that's given, as you would assume, by the time it takes for half of the particles to decay. So N of tau 1/2 is equal to the number of initial particles, N0 over 2. And you find, then, that this half life is related to the lifetime of the particle with a factor of about 2/3. This leads to some confusion in numerical values sometimes when you ask for specific answers from up here, in experiments.

All right, so there's another aspect of decays which arises, which comes from a fundamental property of quantum mechanics. So if you have an unstable state, or any unstable state does not have exact energy state, it just follows, if you want, from the uncertainty principle. So the width of the particle is quantized, and it's quantized with this lambda here. And if you can see, lambda relates, again, to the decay rate or the lifetime of the particle.

Another complication can occur when there's multiple ways for the particle to decay. For example, you have a Higgs boson as we see on the next slide, which might decay into multiple-- has a way to decay into multiple particles. Here, we define a partial width, where the partial width is defined as half the width of the particle to decay into a specific mode. And then the total width of the particle is given by the sum of the partial widths of all possible ways for the particle to decay.

Using this, you can also calculate the likelihood of a particle to decay in a specific way. That's called the "branching fraction." And that's given by the partial width divided by the total width, or the partial decay weight divided by the total decay rate. Again, the total has to be 1, the probability for a particle to decay in any mode is 1. Therefore, the sum of the branching ratios is 1 as well.

All right, so looking at a specific example, the Higgs boson is probably my favorite example in this entire class. You find here, given branching fractions or ratios of specific decay modes, because it's not always in which the Higgs boson decay, but the most dominant one. The most prominent one is the one with Higgs boson decays into a pair of b quarks.

We will later see, maybe even as an exercise, why the distribution function of branching ratios is the way it's being shown here. The Higgs boson has been measured with a mass of 125 gV and a little bit. And you see at this mass here, the prominent decay mode is simply the b bar, but it's also possible for the exponential to decay into a pair of W bosons, where an interesting loop diagram into gluons.

Even so, gluons are massless, or tau, charm, Z bosons, and so on. And we just showed you in a paper which was submitted today to the arXiv, the Higgs boson also can decay into a pair of muons with a branching ratio of 2 times 10 to the minus 4. So it's rather rare, but it's possible.