MARKUS KLUTE: All right, hi. So we continue the discussion in 8.701 on units. So this unit is on units. Why this is an important discussion is because it is very convenient and it simplifies life quite a bit if one does not use SI units in the discussion of, in particle physics, decays in particle physics, or cross-sections. And it's also important to avoid carrying around large exponents. And given, you have a conversation, you want to talk about things which are order of 1 of things instead of 10 to the minus 28 things.

And one example is the introduction of a new unit for the cross-sections of-- units for cross-sections which describes an area, and that unit is barn. We talk about cross-sections of barns, or femtobarns, or picobarns, and one bar is defined as 10 to the minus 28 square meters. Physics processes, the one at high energies-- for example, the ones we discuss at the Large Hadron Collider-- are typically of the order of picobarn, 10 to the minus 12 barns, or one femtobarn, 10 to the minus 15.

So there's an interesting story to barns and why this was introduced. The unit came out of the Manhattan Project. The idea of the scientist was to confuse potential spies towards what cross-sections for nuclear processes are. And so they introduced this unit of a barn, and they're trying to characterize nuclear collisions, maybe an accelerator shooting something at a target. And one barn is a cross-section where it's really, really hard to miss-- so a big cross-section.

In this context, also, the shed was introduced. This is not very popular today anymore. And it turns out that this idea of confusing the readers of papers or of discussions turned into a new standard. So we talk about, of course, barns, and picobarns and femtobarns, specifically, quite frequently.

So this is just one example. This is not really changing the units, but just avoiding carrying around exponents. But we also, in particle physics and in nuclear physics, use a system called natural units. This system is based on fundamental concepts of quantum mechanics and special relativity. So the idea here is that we replace kilogram, meters, and seconds by h-bar, which is a unit of action in quantum mechanics, c, the speed of light, and GeV, where GeV, a typical GeV, is a typical approximate mass of a proton.

So then, you do this transformation, and then you simplify the option of setting h-bar and c to 1, you find that energies are expressed in GeV, momentum is expressed in GeV, and mass is expressed in GeV. That means when you talk about relativistic equations, E equals m c squared and all those things, m, E, and also the momentum have the same unit. That simplifies quite a bit. Time has a unit of 1 over GeV, length has a unit of 1 over GeV, and area has the unit of 1 over GeV squared.

So that's the simplification. You might think that you lose information by setting fundamental constants to 1, but you actually do not, because you carry with you, in your equations, the dimension of the problem. If you want to do a quick exercise here, I invite you to calculate the charge radius of the proton, which is 4.1 over GeV, or per GeV, and convert this back to SI units.

Again, it seems like we lost information here, but just from the dimensional analysis, you can figure out what the answer is. And the hint here is that h-bar c is equal to 0.197 GeV femtometers. So you should already know the answer from previous discussions in the lecture, but the calculation is rather straightforward.

On top of this, it's useful to use Heaviside-Lorentz units and combine them with some measurable units we discussed. So what we do in addition here is set, say, permittivity in free space to 1, and also the permeability in free space to 1-- so epsilon0 and mu0 to 1. When you do that, you basically combine or tie the electric charge to the strength of QCD.

And so alpha, the strength, a dimensionless fine structure constant, 1 over 137, becomes e squared, the electric charge squared, over 4 pi. So this is also very convenient, to have this kind of convention. So we'll use those natural units as we go through class. In some examples, we'll use SI, in others, use natural units. This will always be clear from the problem we're looking at.