MARKUS KLUTE: Welcome back to 8.701. So in this lecture, you want to look at hadron colliders very briefly as an introductory lecture to this topic, but also as the conclusion of the discussion we had in QCD.

So historically speaking, hadron colliders might have been the tool in order to probe the energy frontier. So, and that has to do with accelerator technology, the fact that heavy particles emit less synchrotron radiation allows them in circular colliders to be collided at higher energies.

This plot here shows as a function of year the energy of the constituents. So these are the elementary particles used in the interaction, or the energy of the quarks and gluons being part of the interaction.

And you see that typically we find that hadron colliders, here in red, have an edge over lepton colliders in terms of the maximum collision energy. So the energy frontier usually is given by the hadron collider as compared to the lepton colliders. The protocol is a Livingston plot, and it's a little bit old. We are now here in 2020. We haven't built this machine yet. We might build a lepton collider at 250 GB in 10 years from now or 15 years from now. And also, the LHC is very stable at this energy here.

But the point of this lecture is more to discuss how we can make a cross-section calculation of important photon collisions. So we have already seen how we can make this cross-section calculation where we have, let's say, an initial quark and an anti-quark colliding with exchange of a photon. We haven't seen how we can do this with a Z boson. But we'll see that next week.

This process is called Drell-Yan production. And we're looking at the decay either of the photon--virtual, so virtual photon, or the Z boson and a pair of leptons, electrons, and muons at highest.

So we can calculate this. And we call this cross-section the hard scattering cross-section-- the cross-section of this hard scattering process.

But we need to, in order to calculate this, know the momentum distribution and the abundance of the initial quarks and anti-quarks. And so we do this using the structure from the parton distribution functions, as we discussed them before.

We have to integrate. And those are labeled here with those q's. We have to integrate them over all possible momentum. And we have to sum over the quark species inside the proton.

For this process, we don't have to consider the gluon. Because of leading order, we cannot produce a lepton pair with gluons. Higher orders, we also have to consider gluon densities in this discussion.

And then the momentum of the parton collision has to be equal to the momentum-- the center of mass energy considered in the parton cross-section. This process, this technique, here is called factorization. So we factorize the hard shattering process from the structure of the proton in the cross-section calculation.