Many (all) the questions have been answered during the Q&A period. Nevertheless, we ask that you provide written answers below so students can come back to read them again. Thanks!

1. (Page 21). Could you please explain the anomalous moment curve?

This curve represents a different model used at the time to think about the proton. Essentially, it's a modification of the Mott formular for a point like particle but takes into account the anomalous magnetic moment of the proton as a point particle.
I did not discuss this model in my lecture.

2. (Page 25). Is the charge radius of a proton a Lorentz invariant quantity? The way the charge density is defined does not seem to be Lorentz invariant, hence there seems be a length contraction. Could you please clarify it more?

The charge radius is typically defined in the rest-frame of the proton.

3. (Page 2). Two up quarks with two different color charges (or chiralities) are two different particles, in that sense we end up with a Standard Model with 103 elementary particles. Don't you think that we are in a particle zoo again?

   I think this depends on your taste . The fact there are many up quarks with different colors and different chiralities just means that the up quarks can cary different quantum numbers. The mechanism to describe them remains the same and the quantum numbers are distributed without preference. In my opinion having many different masses of different particles is a bigger problem: seemingly arbitrary values for the masses, not clear why they are distributed as they are, no quantisation.

4. (Page 42). What is a non-abelian gauge theory?

Non-abelien gauge theories are particular gauge theories with a non-abelian symmetry group describing how local complex phases of change from one space time point to the other.
One key consequence is that in non-abelian gauge theories the force carriers – gluons – can interact with each other. This is very different from Quantum Electro Dynamics where photons can NOT interaction with each other directly

5. (Page 43) In the renormalization group equation is it nf=3 or nf=6?

The number of flavors changes depending on how many dynamic degrees of freedom are acting in our problem. Once we have enough energy in a process to for a quark to be created – typically the mass of this quark – then we treat the quark as active.
For example, for Q<172 GeV we say the top quark is not a dynamic degree of freedom and we set nf=5. For Q>173 GeV, nf=6

6. Can you please elaborate more on Bjorken scaling?

   Form factors parametrize the deviation of a scattering cross section from the one of scattering of point-like particles as we increase the energy scale we are probing at. In DIS we scatter point like quarks and point like electrons – i.e. point particles. Consequently, the form factors become independent of the energy scale at which we scatter the particles. This results in the form factors becoming independent of Q, which is referred to as Bjorken Scaling.

7. In the end speaking of point-like particle and elementary, is it only possible for free particles?

   Elementary degrees of freedom are simply the ones we choose to compute with. We know how to compute things well with free particles as asymptotic states, like scattering cross sections. Nevertheless, computations of quantities in bound objects are possible.

8. Why are gluons massless? About gluon masslessness, can we relate that to the range of the strong force?

   First and foremost: that agrees with experiment. Second, if we want QCD – a local gauge theory, to describe these interactions, a mass term would spoil gauge invariance. We could get around that problem (for example with the Higgs mechanism), but this would not be the SM anymore.

   Massless force carriers can be used in order to mediate long range forces – see for example gravity and electro-magnetism. In the case of QCD and the gluon, the strong force confines and essentially disappears as soon as we go to very low energies (<1GeV). As a result, the nuclear force is only visible at similar length scales of ~ 0.1 GeV.

9. Regarding the elementarity of particles, is there any reason why we consider the muon as an elementary particle except that it's a field in our lagrangian?

Muons are really just like copies of the electron. We see no substructure, all the same quantum numbers, only the mass differs. We see it in experiment. So, it is a true degree of freedom and we need to take it along. Consequently, it is an elementary particle in our Standard Model.