Gluon saturation effects in heavy quark production

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Hadrons such as protons consist of valence quarks and a sea of gluons and virtual quarks. At higher energy scales, additional gluons are emitted increasing the gluon density of the hadron. The gluons contribute to interactions with other hadrons, so high gluon density leads to large scattering cross sections. However, the cross sections cannot grow too much without breaking the unitarity of quantum chromodynamics (QCD), so at some energy scale the increase in gluon density must be suppressed. This phenomenon is called gluon saturation.

Clear evidence of gluon saturation has not yet been found. To observe gluon saturation, the difference between the theoretical predictions of saturation models and non-saturation models must be large enough to be resolved by experiments. This study calculates the theoretical cross section predictions for a specific heavy quark producing hadron scattering process that has been recently measured at the Large Hadron Collider (LHC) using lead ions.

In the process in question, one of the hadrons emits a photon that fluctuates into a quark antiquark pair called a colour dipole. The colour dipole then interacts with the other hadron called the target through an exchange of one or two gluons. The one gluon process is inclusive, while the process with two gluons is diffractive. The interaction between the gluons and the target depends on the gluon density of the target and therefore on saturation. The diffractive process includes two gluon target interactions, so it’s more sensitive to saturation.

The photon fluctuation is described by perturbative QCD, but the dipole target interaction depends on a non-perturbative dipole amplitude. Fortunately, the energy evolution of the dipole amplitude can be predicted using perturbative evolution equations. These equations determine the dipole amplitude at any energy scale based on a fit to measurement data at an initial energy scale. Dipole amplitudes for the different models have been computed by Jani Penttala, and the rest of the calculation is done using Monte Carlo integration.

Predictions are first compared with old Hadron–Electron Ring Accelerator (HERA) proton–photon scattering measurements. The predictions and measurements are found to agree on the most relevant parts of the parameter space. This validates the prediction method.

In the LHC prediction, the difference between saturation and non-saturation models is found to be potentially significant for diffractive charm production, while in other processes the difference is relatively small. The analysis of the LHC measurement is ongoing, so it will depend on the final measurement precision whether or not the difference between the models is sufficient to provide clear evidence of gluon saturation.