Measurement of charm production in deep inelastic scattering at HERA II

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Chapter 1

Introduction

Matter and forces in nature

Through the eye of the particle physicist, nature is regarded as matter continuously interacting with itself within a flat space-time. The matter interactions are mediated by three distinct forces: the electromagnetic, the weak nuclear and the strong nuclear forces. The fourth force known in nature, gravity, is significantly weaker at sub-atomic scales. Atoms of different chemical elements consist of the same elementary building blocks: a nucleus composed of neutrons and protons and a cloud of electrons orbiting the nucleus. The neutrons and protons are themselves complex compounds, made of quarks.

Quarks are elementary particles which as yet have no further internal structure. They can never be observed directly but only confined in hadrons. In total, there are six different quarks. Their anti-particles also exist and are called anti-quarks. Baryons, like the neutron or the proton, are bound states of three quarks ($qqq$). Bound states of a quark and an anti-quark are called mesons ($q\bar{q}$).

The three forces mediating interactions can be described by the exchange of particles: the photon, the three gauge bosons and the eight gluons are the forces’ messengers through which matter bits interact with each other. A classification of elementary particles is given in Table 1.1. Both the lepton and the quark sectors are organized in three families which feature similar quantum numbers but very different masses. The lightest of the three families is formed by the electron, the electron neutrino and the up and down quarks. These are the particles which constitute the matter around us. Particles belonging to the other two families are formed in high-energy interactions and quickly decay to particles of the first family.
Table 1.1. Classification of elementary particles. The fermions constitute matter. The bosons are the force carriers.

The Standard Model is the most advanced quantum theory known yet which describes how elementary particles interact. It incorporates all elementary particles as well as the electromagnetic, weak and strong nuclear forces in one mathematical framework. The Standard Model has been confirmed experimentally to great accuracies. Nevertheless, there are many questions for which this theory cannot provide an analytic answer and, for few other questions, no answer at all. For instance, it is not known why elementary particles have precisely the masses that we observe they have.

The proton

The most abundant element in the Universe is hydrogen, which constitutes about 3/4 of the luminous matter\(^1\). The proton is the nucleus of the hydrogen atom. Protons were created in large numbers at about 10\(^{-6}\) seconds after the Big Bang. They are believed to be stable\(^2\). The proton is built from three valence quarks (uud) which carry the proton quantum numbers. These quarks are kept together by the strong force. The quarks constantly radiate and absorb gluons which, in turn, can split into pairs of quarks and anti-quarks or other gluons. This virtual sea

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\(^1\)Only 4\% of the total energy density in the Universe consists of luminous matter. The rest is thought to be dark matter (22\%) and dark energy (74\%).

\(^2\)The experimental lower limit on the proton’s lifetime is 10\(^{35}\) years.
of quarks and gluons determines many of the proton’s properties. Quantum chromodynamics (QCD) is an advanced quantum theory, itself part of the Standard Model, which describes interactions of quarks and gluons.

The inner structure of the proton can be studied in great detail with electron-proton scattering. HERA, an $e^-p$ collider, accelerates both protons and electrons to extremely high energies and then collides them against each other. From the resulting collision fragments, information can be inferred about the structure of the proton, while at the same testing predictions of QCD.
Introduction