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052178039X - Pomeron Physics and QCD

Sandy Donnachie, Gunter Dosch, Peter Landshoff and Otto Nachtmann

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# Pomeron Physics and QCD

This book describes the underlying ideas and modern developments of Regge theory. It confronts the theory with a huge variety of experimental data and with quantum chromodynamics. The book covers forty years of research and provides a unique insight into the theory and its phenomenological development. It provides comprehensive coverage of the various different theoretical approaches and considers the key issues for future theory and experiment.

The authors review experiments that suggest the existence of a soft pomeron and give a detailed description of attempts to describe this through nonperturbative quantum chromodynamics. They suggest that a second, hard pomeron is responsible for the dramatic rise in energy observed in deep inelastic lepton–nucleon scattering. The two-pomeron hypothesis is applied to a variety of interactions and is compared with perturbative quantum chromodynamics, as well as with the dipole approach.

This book will be a valuable reference for theoretical and experimental particle physicists all over the world. It is also suitable as a textbook for graduate courses in particle physics, high-energy scattering, QCD and the standard model.

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## Preface

In 1935 the Japanese physicist Hideki Yukawa predicted that there must be a particle, now known as the pion, which would transmit the strong interaction. The pion was duly discovered more than ten years later. However, we now know that although pion exchange is an important component of the static force, when the force acts between a pair of particles with high energy a very large number of particles collaborate in transmitting it. Regge theory provides a simple quantitative description of the combined effect of all these particle exchanges.

It was soon realised that the exchanges of the known particles, even though several hundred are listed in the data tables, are not sufficient to describe a striking feature of the strong force: that it retains its strength as the energy increases and even becomes yet stronger. To explain this, it must be that something else is exchanged. This new object was named after the Russian physicist Isaac Pomeranchuk. It was originally called the pomeranchukon, but this was later abbreviated to pomeron. Events in which a pomeron is exchanged are often called diffractive events. The reason for this is that pomeron exchange dominates in high-energy elastic scattering and, as we describe in chapter 3, when plotted against scattering angle the differential cross section has a striking dip, reminiscent of the intensity distribution in optical diffraction. However, we explain that actually the mechanism for dip generation in high-energy scattering is more complicated than in optical diffraction.

During the 1960s it was found that, with the inclusion of the soft pomeron, Regge theory provides a very successful description of a huge quantity of experimental data. This was summarised by Collins in his classic book[1], which was published in 1977. However, the phenomenology appeared to be complicated. It was not until the 1980s that it became apparent that the



reason for this was that the early data were at comparatively low energies. When the rather-higher-energy data became available from the CERN ISR, and later on from the CERN  $\bar{p}p$  collider, the phenomenology became much simpler[2], indeed considerably simpler than the known theory was able to explain.

Meanwhile, quantum chromodynamics (QCD) had been discovered in the early 1970s. It was natural to try to explain the pomeron in terms of QCD, and first attempts to do so were made by Low[3] and by Nussinov[4]. These attempts were refined over the years within the framework of perturbative QCD, notably by Cheng and Wu[5] and by Lipatov and his collaborators[6]. However, it is rather clear that the pomeron that controls the high-energy behaviour of soft hadronic reactions cannot be described by perturbation theory and work began[7] in the late 1980s on the very difficult task of modelling it through nonperturbative QCD. Even now, we still cannot claim that we have more than a rough description of the pomeron in terms of QCD.

Towards the end of the 1960s experiments had begun at the Stanford Linear Accelerator. These scattered electrons on protons and studied the rare events in which the electron momentum transfer was large. Although such events were comparatively rare, they were sufficiently copious to show that the proton contains a number of small scattering centres, which we know now to be quarks. In a real sense, these experiments marked the beginning of modern high energy physics. At the beginning of the 1990s similar experiments, but at a very much higher energy, began at the electron-proton collider HERA in Hamburg. These experiments made the quite dramatic discovery that the probability of the occurrence of large-electron-momentum-transfer events grows very rapidly with energy. At first, this was believed to be a triumphant confirmation of the perturbative-QCD calculations. That is, it suggested that actually there are two pomerons, the “soft” nonperturbative one which is responsible for the fairly gentle rise with energy of soft hadronic reactions, and a “hard” perturbative one responsible for the dramatic rise with energy of the large-electron-momentum-transfer scattering probability. Unfortunately, it was then found that the perturbative-QCD calculations receive very large nonleading-order corrections, so that the agreement between theory and experiment was lost. At present, there is no generally-accepted explanation of the dramatic HERA behaviour.

The electron-scattering experiments explore the structure of the proton. Ingelman and Schlein suggested[8] that a special class of electron-scattering events might also study the structure of the pomeron (or pomerons), thereby creating the topic of hard diffraction. This has been an active area of study

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at HERA; it actually began at the CERN  $\bar{p}p$  collider and is continuing at the Tevatron at Fermilab.

All these things are the subject of our book, which draws together a huge amount of knowledge gathered at existing and past accelerators, as a preparation for the beginning of the operation of RHIC at Brookhaven and the Large Hadron Collider at CERN.

We have set up a web page in connection with this book:

<http://www.damtp.cam.ac.uk/user/pvl/QCD/>

We will use this to record corrections to the book, and perhaps some updates. It also makes available all the figures, which we are happy for others to use with due acknowledgment.

We wish to pay tribute to the Durham database,

<http://www-spires.dur.ac.uk/HEPDATA/>,

which we have used extensively to create our figures, particularly those for which the sources of the data have not been explicitly referenced.

We record with gratitude also that the research of AD and PVL has been supported in part by the UK Particle Physics and Astronomy Research Council, and the research of HGD and ON by the German Bundeministerium für Bildung und Forschung, which also has largely funded our meetings to prepare this book.

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