Experimental Diffraction from HERA to the LHC

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Since 2004, a series of workshops has taken place on the implications of HERA for LHC physics. The concluding meeting was held in May 2008. This document summarises the main outcomes in the area of experimental diffraction.

1 Introduction

Our understanding of rapidity gaps and colour singlet exchange in terms of the fundamental quarks and gluons of the strong interaction has developed substantially over the past 15 years through the study of hard diffractive processes at HERA. It is becoming increasingly apparent that diffraction will also be a topic of considerable interest at the LHC, both in its own right and as a selection or search tool for rare or exotic processes. This contribution [1], takes an experimental perspective in summarising the connections between diffraction at HERA and at the LHC and emphasises areas where recent work on HERA data is contributing most strongly to preparations for LHC diffraction. Further details, including more theoretical aspects, are discussed in [2].

2 Inclusive Diffraction and Diffractive Parton Densities

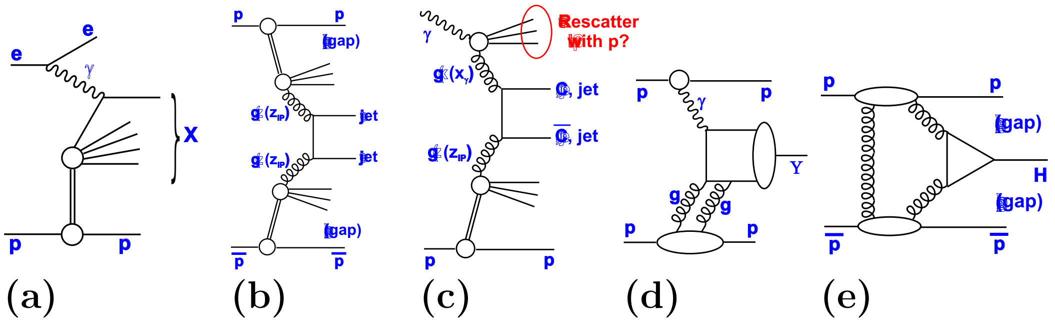

Figure 1: Illustrations of some diffractive ep and pp processes: (a) inclusive diffraction at HERA; (b) dijet production via 'double pomeron exchange' at the LHC; (c) dijet photoproduction at HERA; (d) Υ production at the LHC via ultra-peripheral $\gamma I\!P$ fusion (two-gluon exchange model); (e) central exclusive Higgs production at the LHC.

The parton level structure of diffractive exchange is usually expressed in terms of Diffractive Parton Distribution Functions (DPDFs), which can be extracted from the cross section for the deep inelastic scattering (DIS) process $ep \to eXp$ at HERA (figure 1a). There is now rather good agreement on the diffractive cross section between H1 and ZEUS and between measurements using selection methods with very different systematics [3]. This consensus is reflected in a correspondingly improved agreement on the DPDFs, which have been extracted recently by several groups [4, 5, 6, 7] in the framework of next-to-leading order (NLO) DGLAP evolution. The DPDFs are an essential ingredient in calculating a wide range of hard diffractive LHC processes such as that shown in figure 1b.

An example set of DPDFs [4] is shown in figure 2, as a function of the momentum fraction z of the parton entering the hard scattering. The diffractive quark density and the gluon density at low to moderate z are well constrained from the inclusive cross section alone. However, the sensitivity to the gluon density from the inclusive process is lost at large z, which is among the most important regions for LHC studies (see section 4).

The DPDFs extracted from inclusive diffraction at HERA lead to a good description of numerous observables in diffractive DIS, including charged current cross sections and heavy flavour yields. The most exacting tests come from the production of pairs of jets within the system X, which is directly sensitive to the diffractive gluon density via the 'boson-gluon fusion' process $\gamma^* g \rightarrow q\bar{q}$. When included in the QCD fits, dijet data add considerably to the constraints on the high z gluon [7], though interpreting this region remains problematic theoretically [5].

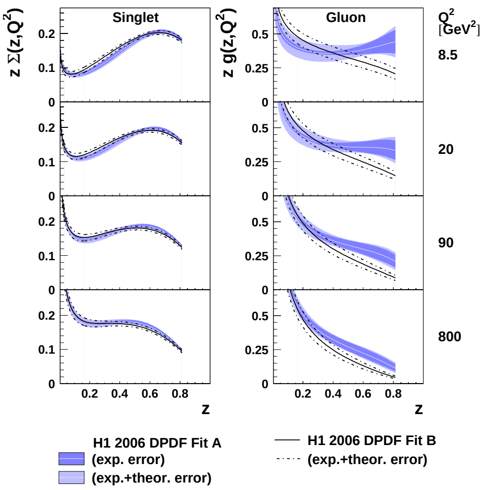

Figure 2: Example diffractive PDFs extracted from inclusive diffraction at HERA [4].

3 Rapidity Gap Destruction and Factorisation Breaking

Factorisation is expected to break down due to rescattering (or 'absorptive') effects wherever hadronic remnants are present, a phenomenon which is now well established in comparisons between HERA and Tevatron data [8]. A 'gap survival probability' factor must therefore be included in diffractive hadron-hadron scattering cross section calculations based on DPDFs. All diffractive processes at the LHC, including those in figure 1, are affected, with survival probabilities estimated to be no more than a few percent [9]. Understanding the detailed physics of gap destruction is thus vital to the preparations for diffractive studies at the LHC.

Although gap survival is not an issue in DIS (figure 1a), nor in 'direct' photoproduction, the 'photon remnant' in 'resolved' photoproduction (figure 1c) may lead to rescattering. Photoproduction thus provides a control experiment in which the onset and nature of absorptive gap destruction may be investigated. The effect has now been established in leading neutron studies [10] but the most quantitative and intriguing results have emerged from dijet photoproduction measurements. When comparing data with NLO predictions which do not account for gap destruction effects, neither H1 [11, 12] nor ZEUS [13] observe any significant difference between the quality of the description of resolved and direct photoproduction. However the overall survival probability was initially reported to be different between H1 and ZEUS. An explanation for this apparent discrepancy is found in a dependence on the jet transverse energy, which has now been observed by both collaborations and in three independent data samples (figure 3) [11, 13, 12]. As yet there is no theoretical consensus on the origin of this effect [14], though it arises naturally if the 'size' of the photon (and hence the rescattering probability) is taken to be conjugate to the largest scale in the problem (here the jet transverse energy), rather than simply to Q^2, as is normally assumed.

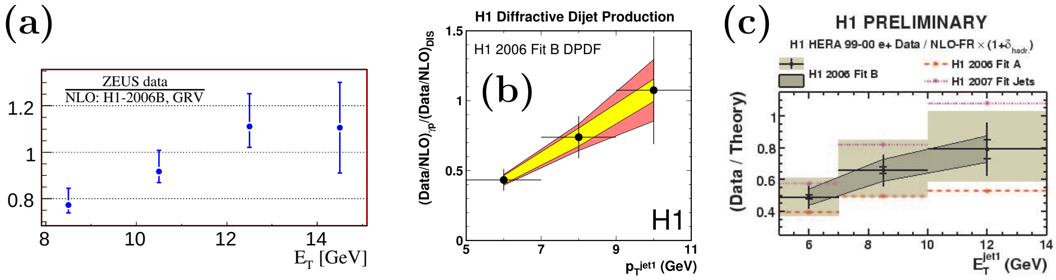

Figure 3: Ratios of data to NLO predictions (with gap destruction effects neglected) as a function of jet transverse energy in three HERA measurements of diffractive dijet photoproduction: (a) [13]; (b) [11] and (c) [12].

4 Exclusive Diffraction

Exclusive photon and vector meson production has been studied in great detail at HERA. In addition to what they have taught us about elastic scattering and photon interactions [15], these channels constrain the generalised gluon density, an essential ingredient for central exclusive diffractive studies at the LHC (see below).

Exclusive central production at the LHC is sensitive to $\gamma\gamma$, $\gamma I\!\!P$ (figure 1d) and $I\!\!P I\!\!P$ interactions, all of which give rise to interesting physics possibilities [16]. Taking the $\gamma I\!\!P$ case as an example, there is complementarity between HERA and the LHC, with HERA providing precise ρ and J/ψ data, but low Υ yields, whereas there are encouraging prospects for exclusive Υ studies at low luminosity at the LHC [16].

Perhaps most interesting among exclusive production possibilities at the LHC are processes such as figure 1e, which have been discussed at length in terms of exclusive Higgs production. Predicting LHC yields for the Higgs process requires a knowledge of the generalised gluon density and of gap survival probabilities. The background from inclusive processes similar to figure 1b depends on the high z DPDFs. The theoretical tools for central exclusive production at the LHC have been sharpened using related processes at the Tevatron, where the Higgs in figure 1e is replaced by a pair of jets or photons [17]. The outcome is a predicted exclusive Higgs cross section at the LHC of around 3 fb, including a 3% gap survival probability [9], making it an accessible channel at high luminosity.

5 Instrumentation for Diffraction at the LHC

There has been a huge effort to prepare for diffractive physics at the LHC [18], with a correspondingly large number of detectors, installed, approved and proposed [19]. The combined instrumentation of the CMS CASTOR and Zero Degree calorimeters with two very forward sets of tracking detectors and Roman pots at TOTEM will provide excellent coverage, especially if supplemented by the FP420 Roman pot detectors at 420 m. Similarly, a view along the beam-pipe from ATLAS in a few years time may incorporate the LUCID and Zero Degree calorimeters as well as the ALFA and ATLAS-FP Roman pots at 220 m, 240 m and 420 m. Preparations for diffractive studies at ALICE are also well underway. Figure 4 shows the acceptances of the proposed ATLAS Roman pot detectors for central exclusive Higgs production (the TOTEM / CMS acceptance is similar.).

In the early phases of LHC operation, before event pile-up becomes an issue, diffractive events can be selected not only by tagging leading protons, but also on the basis of rapidity gaps, as was done successfully at HERA and the Tevatron. As pile-up becomes more of an issue, rapidity gaps will be obscured by additional non-diffractive pp interactions, and selection on the basis of scattered protons will become imperative. Unambiguously correlating the scattered protons with high transverse momentum activity in the main detectors may be possible by reconstructing the vertex position to within a few mm using picosecond timing detectors in the Roman pots [20].

Finally, the longer term idea to introduce an electron accelerator to the LHC [21], facilitating ep collisions at $\sqrt{s} = 1 - 2$ TeV, would be a major step forward for low x physics in general, giving access to Bjorken-x values below 10^{-6} for $Q^2 > 1$ GeV^2. The evaluation of the potential impact on diffractive physics is in its infancy.

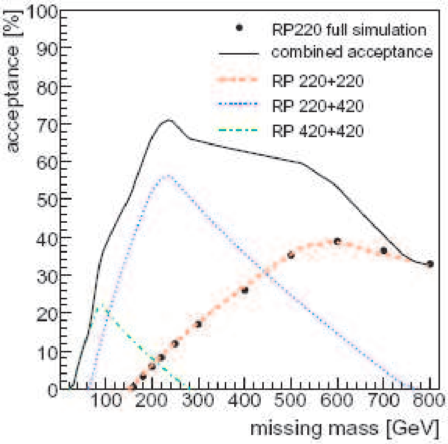

Figure 4: ATLAS acceptance for central exclusive Higgs production (figure 1e) as a function of Higgs mass, assuming Roman pots at 220 m and 420 m.

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