Early LHC measurements to check predictions for central exclusive production

V.A. Khoze1,2,a, A.D. Martin1, M.G. Ryskin1,2

1 Institute for Particle Physics Phenomenology, University of Durham, Durham, DH1 3LE, UK
2 Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg, 188300, Russia

Received: 4 February 2008 / Revised version: 4 March 2008 / Published online: 9 May 2008
© Springer-Verlag / Società Italiana di Fisica 2008

Abstract. We show how the early data runs of the LHC can provide valuable checks of the different components of the formalism used to predict the cross sections of central exclusive processes. The ‘soft’ rapidity gap survival factor can be studied in electroweak processes, such as $W +$ gaps events, for which the bare amplitude is well known. The generalised gluon distribution, in the appropriate kinematic region, can be probed by exclusive $T$ production. The perturbative QCD effects, especially the Sudakov-like factor, can be probed by exclusive two- and three-jet production. We discuss the possible role of enhanced absorptive corrections that would violate the soft–hard factorisation implied in the usual formalism, and we suggest ways that the LHC may explore their presence.

1 Introduction

Central exclusive production is now recognised as an important search scenario for new physics at the LHC; see for instance, [1–9] and references therein. The experimental studies of such processes are at the heart of the FP420 project [8,10], which proposes to complement the CMS and ATLAS experiments at the LHC by installing additional forward proton detectors 420 m away from the interaction region. In particular, these detectors will allow for the measurement of the exclusive production of new heavy particles, such as Higgs bosons. As demonstrated in [11–14] such measurements will be able to provide valuable information on the Higgs sector of MSSM and other popular BSM scenarios.

Indeed, central exclusive processes are very interesting both from the viewpoint of theory, since they contain a mixture of soft and hard QCD effects, and of experiment, as they provide a clean environment to measure the quantum numbers and masses of new objects that may be seen at the LHC. Moreover, the $J_z = 0$ selection rule ($J_z$ is the projection of the total angular momentum along the proton beam direction), arising in central exclusive diffractive processes [3,15], provides a unique possibility to study directly the coupling of the Higgs-like bosons to the bottom quarks, because the LO QCD background is strongly suppressed by the $J_z = 0$ rule. 2pt As is well known, the determination of the $H bb$ Yukawa coupling appears to be very difficult for other search channels at the LHC.

The theoretical formalism [1,16,17] needed to describe a central exclusive diffractive process of a system $A$ contains quite distinct parts, shown symbolically in Fig. 1. In brief, we first have to calculate the $gg \rightarrow A$ hard subprocess, $H$, convoluted with the gluon distributions $f_g$. Next we must account for the higher loop corrections, which reflect the absence of additional QCD radiation in the hard subprocess – that is, for the Sudakov suppression factor $T$. Finally, we must enter soft physics to calculate the survival probability $S^2$ of the rapidity gaps on either side of $A$ – that is, the probability that the exclusive nature of the process will not be destroyed by the secondaries produced by the rescattering of the incoming particles.

2 Objective

The uncertainties associated with the prediction of the rate of a central exclusive process are potentially not small. Each of the above stages has its own uncertainties. Therefore, it is important to perform checks of the approach using processes with appreciable cross sections that will be experimentally accessible in the first data runs of the
LHC with integrated luminosities in the range 100 pb$^{-1}$ to 1 fb$^{-1}$. Here, our aim is to identify processes in which the different ingredients of the formalism used to calculate central exclusive production can be tested experimentally, more or less independently.

The outgoing protons in the forward regions of the main LHC detectors will be measured by the forward proton taggers (roman pots). At 220 m on either side of the CMS detector there exists the roman pots of the TOTEM experiment [18, 19]. ATLAS will have the ALFA detector [20, 21] at 240 m as well as the proposed RP220 detector [22] at 220 m. As we already mentioned, the FP420 project [8, 10] proposes to install forward proton taggers for both ATLAS and CMS. Note that RP220 and FP420 aim to operate at high luminosities. However, it is quite likely that for the first 1–2 years of LHC running, the forward proton detectors will not be operational. We therefore first consider measurements that do not rely on tagging the forward-going protons.

Even without proton tagging, diffractive measurements at the LHC can be performed through the detection of rapidity gaps. This is a well known technique used extensively at HERA and the Tevatron. A summary of the forward detectors instrumented around ATLAS and CMS is given, for instance, in [23–25]. The central detectors (CD) of CMS and ATLAS have an acceptance in pseudorapidity $\eta$ of roughly $|\eta| < 2.5$ for tracking information and $|\eta| < 5$ for calorimeter information. We will discuss the situation where a heavy system $A$ is detected in the region $|\eta| < 2.5$, and where the calorimeters in the $2 < \eta < 5$ interval are used to select events with rapidity gaps.

In the present paper the word *gap* means a rapidity interval $\Delta \eta$ devoid of hadronic activity – for the charged particles we assume a ‘track veto’, while the absence of neutrals will not be checked by the calorimeters. The amplitudes of all the processes discussed below are infrared stable and are not affected by the possibility of soft gluon emission.

Due to angular ordering, which originates from coherence, in those processes in which the gap is provided by $W$ boson exchange (as in Fig. 2a and c below), the only possible soft gluons occur at the edge of the gap and arise from the corresponding quark jet. These gluons should be accounted for in the jet searching algorithm. In cases where the gaps are associated with a colour singlet, two-gluon exchange (as in central exclusive dijet production), the presence of Sudakov-like $T$-factors in the unintegrated gluon distributions (see (7) below) guarantees that there is no emission of any additional soft gluons.

The selection of rapidity gap events by a ‘veto’ trigger can be used up to rather large luminosities, when the mean number, $N$, of interactions per bunch crossing is sizeable. However, at larger luminosities the efficiency of the trigger is reduced by a factor $e^{-N}$ – that is, by the probability to have no additional ‘pile-up’ inelastic interaction in the bunch crossing. This probability can be measured independently in the same experiment.

Of course, the proposal to use calorimeters in the $2 < \eta < 5$ interval to select the events with a rapidity gap does not mean that we will only consider gaps with $\Delta \eta < 3$. First, part of the gap can be at smaller $\eta$ and, secondly, extensive additions are foreseen to enlarge the coverage in the forward regions.1 Possible “holes” in particle observation in small rapidity intervals between different calorimeters do not affect our predictions very much. The probability to produce extra soft hadrons in the hole region only is proportional to the effective pomeron–pomeron cross section, which is rather small, according to the triple-Regge analysis of the UA8 data [27]. We evaluate the correction to be less than 3% for a hole of size $\Delta \eta_{\text{hole}} \sim 1.5$.

The main uncertainties of the predictions for exclusive processes are associated with the calculation of the following.

(i) The probability $S^2$ that additional soft secondaries will not populate the gaps separating the centrally produced system $A$ from the outgoing protons (or the products of their dissociations).2

(ii) The probability to find the appropriate gluons that are given by generalised unintegrated distributions $f_3(x, x', Q^2)$.

---

1 CMS will have the CASTOR calorimeter operating with the coverage of $5.1 < \eta < 6.5$ and a Zero Degree Calorimeter (ZDC) with an acceptance for neutral particles with $\eta > 8$. Both calorimeters have an electromagnetic and hadronic section. Moreover, CMS is expected to have integrated read out with TOTEM [18], allowing CMS to benefit from the TOTEM forward coverage and TOTEM, in turn, from the CMS central coverage [19]. ATLAS plans a Cerenkov detector LUCID with an acceptance $5.4 < \eta < 6.1$ and a ZDC with an acceptance $8.3 < \eta < 9.2$. Diffractive studies are under discussion also at ALICE, see for instance, [26]. The ALICE detector has a central barrel covering the pseudorapidity range $-0.9 < \eta < 0.9$ and, on one side) a muon spectrometer covering the region of $2.4 < \eta < 4$ and a ZDC. Additional detectors for trigger purposes and for event classification are placed on both sides of the central barrel, such that the range $-3.7 < \eta < 5$ is covered. This configuration allows for the possibility of a (double) rapidity gap trigger by requiring no activity in the event classification detectors [26].

2 There are quite a few theoretical studies of the $S^2$ factor, starting from the publications [28–30] to more recent ones [17, 31]; see also references therein. Following Bjorken [29, 30] this quantity is often called the survival probability or soft survival factor.