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Diffractive Higgs boson production at LHC

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Abstract

The exclusive double Pomeron exchange production of Higgs boson in diffraction processes is briefly discussed. Three dedicated Monte Carlo event generators are described and their predictions compared. Two decay channels, namely $H \rightarrow b\bar{b}$ and $H \rightarrow W^+W^-$, are discussed in detail.

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1 Introduction

Data from the proton-proton collisions which will be produced at the LHC at the highest-ever centre-of-mass energy, $\sqrt{s} = 14$ TeV, will provide information about unexplored phase space regions and new physics domains. The luminosity at startup, planned for the year 2007, is expected to be $10^{33} \text{cm}^{-2} \text{s}^{-1}$. In the high luminosity mode, it will reach values of $10^{34} \text{cm}^{-2} \text{s}^{-1}$ leading to an integrated luminosity of 100fb^{-1} per year. At these highest luminosities, it is expected to see on average 23 overlapping (mostly soft) hadronic interactions per bunch crossing.

The forward physics project includes the CMS [1], TOTEM [2] and CASTOR [3] detectors. The CMS detector is a general purpose detector with an acceptance of $|\eta| < 3$ for tracking and of $|\eta| < 5$ for calorimetry. The pseudorapidity is defined as $\eta = -\ln \tan(\theta/2)$ where θ is the polar angle of a particle with respect to the beam axis. The TOTEM experiment will use the same interaction point (IP) as CMS and is designed to measure the total and elastic pp cross sections, and the diffraction dissociation. It will use two telescopes to detect inelastic events, namely T1 with an acceptance of $3 < |\eta| < 5$ and T2 with an acceptance of $5.3 < |\eta| < 6.6$ (Fig. 1), and three Roman Pot (RP) stations, placed symmetrically (at 147, 180 and 215 m) from the IP to measure protons scattered under very small θ angles. The CASTOR calorimeter is designed to cover the same region as T2. A combination of these detectors thus provides the largest acceptance detector ever built at a hadron collider and enables a study of a large variety of processes in detail. The issue of a common usage of the TOTEM and CASTOR detectors and their integration into the CMS detector and trigger/DAQ system is being investigated in a common study group established in 2002.

Figure 1: Positions of the T1 and T2 TOTEM telescopes and the CASTOR calorimeter, integrated into CMS.

2 Comparison of Monte Carlo generators

The exclusive diffraction mechanism is defined as $pp \rightarrow p+X+p$ where no radiation is emitted between the outgoing beam hadrons and the central system X. The three generators that are examined here are DPEMC [4], EDDE [5] and ExHuMe [6]. ExHuMe is an implementation of the perturbative calculation of Khoze, Martin and Ryskin [7] in which two gluons couple perturbatively to the off-diagonal unintegrated gluon distribution in the proton. This approach includes a Sudakov factor to suppress radiation between the outgoing protons and the central system X. The bare cross section is suppressed by a rapidity gap survival probability, S^2 , that accounts for additional momentum transfer between the proton lines which could fill in the gap. ExHuMe takes $S^2 = 0.03$ to be at the LHC.

In contrast, DPEMC and EDDE treat the proton vertices non-perturbatively using Pomeron emission from each of the protons. DPEMC follows the Bialas-Landshoff approach [8] of parameterising the Pomeron flux within the proton. DPEMC also sets S^2 to 0.03 at the LHC. EDDE uses an improved Regge-eikonal approach [9] to calculate the soft proton vertices and includes the Sudakov suppression factor. Using the default settings at the LHC energy of 14 TeV, the total cross sections for production of a $120 \text{GeV}/c^2$ Higgs boson are 3.0, 1.9 and 2.8 fb for DPEMC, EDDE and ExHuMe respectively. However, despite these similar values, the physics reach of the central exclusive process is predicted to differ significantly between the generators [10]. Fig. 2a) shows ExHuMe and EDDE predicting that the cross section for the exclusive production of the Higgs boson decreases with the Higgs boson mass (M_H) much faster than in DPEMC. This is a direct effect of the presence of the Sudakov suppression factors growing as the available phase space for gluon emission increases with an increasing mass of the central system. Figure 2b) shows different behaviour of the generators concerning the collision energy dependence of an exclusively produced $120 \text{GeV}/c^2$ Higgs boson. Since with a fixed central mass, an increase in

collision energy is identical to a decrease in $\xi_1 * \xi_2$, the flatter $\sqrt{s}$ dependence of DPEMC and EDDE is reflected in the flatter ξ distributions compared to ExHuMe (Fig. 3a)). The distributions of ξ (ξ_1 and ξ_2 are the momentum losses of both protons measured in the RPs) as well as of the central system rapidity (Fig. 3b)) have a direct impact on the physics potential. The more central rapidity distribution of ExHuMe is due to the gluon distribution falling more sharply than the Pomeron flux parameterisation present in DPEMC. It should, however, also be noted that the selection of the PDF parameterisation has a non-negligible effect. It was observed in ExHuMe that going from the default MRST 2002 set to the CTEQ6M set gives rise a flatter ξ distribution which leads to a broader peak and sharper fall in rapidity distribution and hence a larger cross section of 3.7 fb. Predictions of the cross sections for two decay modes are shown in Fig. 2c). The increasing branching ratio to WW as M_H increases compensates for the falling central exclusive cross section.

The acceptance of any forward proton taggers that might be installed at the LHC are sensitive to the rapidity distribution of the central system. The differences seen in Fig. 3b) are reflected in different acceptance curves shown in Fig. 4. The predicted acceptances using Roman Pots at 420 and 220 m as a function of the mass of the central system were obtained using a fast simulation of the CMS detector. The fast simulation includes a parameterisation of the responses of the Roman Pots based on a detailed simulation of the detectors [11].

Figure 2: The cross section for the exclusive production of the Higgs boson as a function of (a) the Higgs boson mass, (b) the collision energy, (c) the Higgs boson mass (for $H \rightarrow WW$ and $H \rightarrow b\bar{b}$).

Figure 3: The distribution of the a) $\max(\xi_1, \xi_2)$ and b) the Higgs boson rapidity. A cut $\xi_{\max} = 0.1$ is applied in DPEMC, as required by the Bialas-Landshoff approach. Nev is the number of events.

As seen in Fig. 4, as the mass of the central system increases the combined acceptance using detectors at both 220 and 420 m (420+220 m) increases, with the relative difference between the predictions from the three generators decreasing (from about 40% down to 15% for the most extreme relative differences). At $M_H = 120 \text{ GeV}/c^2$ the acceptances are predicted to be 46, 50 and 57% for EDDE, DPEMC and ExHuMe, respectively. Corresponding acceptances for the 420 m detector alone are 24, 25 and 32%, respectively.

Figure 4: The predicted acceptances for the proposed forward taggers at 420 m and for a combination of taggers at 220 and 420 m from the central detector.

Experimental data with which the generators could be confronted are very scarce. The only existing set of results comes from the CDF collaboration [12]. They have experimentally defined exclusive events to be those where $R_{jj} = M_{jj}/\sqrt{\hat{s}} > 0.8$ with M_{jj} defined as the mass of two jets with the highest transverse energy and $\sqrt{\hat{s}}$ is the invariant mass of the central system. It should be noted that M_{jj} depends on the particular jet algorithm used and the $\sqrt{\hat{s}}$ measurement relies on the central calorimeter rather than on forward detectors.

3 $H \rightarrow b\bar{b}$

This decay channel is challenging. The b -jet background is controlled by a combination of the $J_z = 0$ selection rule, which strongly suppresses central $b\bar{b}$ production at leading order, and a very good mass resolution from the Roman Pots using the missing mass method. This method gives resolutions of the order of 1% for a 140 GeV/ c^2 central system, if both protons are detected at 420 m from the IP. For the 420+220 m combination the resolution deteriorates to approximately 6%. The detectors at 220 m alone can accept only central systems with masses larger than 200 GeV/ c^2 . There are three issues in this channel. Firstly, the estimate of the whole background turns out to be very complex [13]. The LO contributions are fully suppressed by the $J_z = 0$ selection rule in the limit of massless quarks and forward going protons. There is an admixture of $|J_z| = 2$ production, arising from non-forward going protons and also contributions of the order of m_b^2/E_T^2 from massive quarks. There are also indications that the NLO contributions are non-negligible, however, they still need to be calculated. Another problem is the acceptance-resolution compromise. If we wish to detect a 120 Higgs boson we can choose from two detecting modes, namely the combination of 220 and 420 m or the 420 m alone. While the former gives a reasonable acceptance and a rather moderate resolution, the latter offers a rather low acceptance and the excellent resolution leading to the efficient background suppression. The third problem is the level-1 triggering. Due to latency requirements, the signal from the 220 m RP arrives in time for a level-1 trigger decision, while that from the 420 m RP does not. The cuts used to trigger diffractively produced $H \rightarrow b\bar{b}$ events (with $M_H = 120$ GeV/ c^2) with a bandwidth of 1 kHz lead to a selection efficiency of 15–20% [14].

4 $H \rightarrow WW$

This channel does not suffer from any of the above problems: suppression of the dominant backgrounds does not rely primarily on the mass resolution of the RPs, it is calculated with a sufficient precision and certainly in the semi-leptonic decay channel, level-1 triggering is not a problem. From experimental point of view, there are three main categories of events with two W bosons in the final state. Events in which at least one of the W bosons decays in either the e or μ are the simplest and will usually pass the level-1 trigger thresholds due to the high p_T final state lepton. If one of the W bosons does not decay in the e or μ channel, the event can still pass the level-1 trigger thresholds if a W decays in the τ channel, with τ subsequently decaying leptonically. The 4-jet decay mode occurs approximately half the time, but is unlikely that this signature will pass the level-1 trigger thresholds without information from the RPs. The CMS level-1 trigger has a single (double) electron threshold of 29 (17) GeV with a pseudorapidity coverage of $|\eta| < 2.5$, falling to 14 (3) GeV for a single (double) muon, with a coverage of $|\eta| < 2.1$. In the semi-leptonic decay channel, two quarks are required to have $p_T > 25$ GeV and $|\eta| < 2.5$ and at least one e (μ) to have $p_T > 20$ (10) GeV. In table 1 we show the event yields per luminosity of 30 fb $^{-1}$ as obtained with ExHuMe. Similar results were obtained for the ATLAS level-1 trigger thresholds [15].

Table 1: Cross sections, acceptances and event yields per luminosity of 30 fb $^{-1}$ for $H \rightarrow WW$ decay channel as obtained with ExHuMe 1.3.

$M_H[\text{GeV}/c^2]$	$\sigma[\text{fb}]$	Acc[%]	semi-lept.[Nev]	fully-lept.[Nev]	Total[Nev]
120	0.37	57	1.2	0.2	1.3
135	0.77	62	3.1	0.6	3.4
140	0.87	63	3.5	0.6	3.8
150	1.00	66	4.9	1.0	5.3
160	1.08	69	6.0	1.0	6.6
170	0.94	71	5.4	1.0	5.9
180	0.76	74	4.5	0.8	4.9
200	0.44	78	2.9	0.6	3.2

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