Monte Carlo generators for central exclusive diffraction

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Abstract
We review the three Monte Carlo generators that are available for simulating the central exclusive reaction, $pp \to p + X + p$.

1 Introduction

The central exclusive mechanism is defined as $pp \to p + X + p$ with no radiation emitted between the intact outgoing beam hadrons and the central system X. The study of central exclusive Higgs boson production has been aided with the recent development of Monte Carlo simulations to enable parton, hadron and detector level simulation. The three generators that we shall examine here are DPEMC [1], EDDE [2] and ExHuME [3]. From an experimental perspective, it is important to examine both the similarities and differences between the models in order to assess the physics potential in terms of forward proton tagging at the LHC [4].

Each of the Monte Carlos implements a different model of central exclusive production that is either perturbative or non-perturbative. ExHuME is an implementation of the perturbative calculation of Khoze, Martin and Ryskin [5], the so-called "Durham Model". In this calculation (depicted in fig 1(a)), the two gluons couple perturbatively to the off-diagonal unintegrated gluon distribution in the proton. The Durham approach includes a Sudakov factor to suppress radiation into the rapidity gap between the central system and the outgoing protons and which renders the loop diagram infra-red safe. The bare cross section is suppressed by a soft-survival probability, $\mathcal{S}^2$, that accounts for additional momentum transfer between the proton lines that lead to particle production that could fill in the gap. The current ExHuME default takes $\mathcal{S}^2$ to be 0.03 at the LHC.

In contrast, DPEMC and EDDE treat the proton vertices non-perturbatively. This is acheived in the context of Regge theory, by pomeron exchange from each of the proton lines. DPEMC follows the Bialas-Landshoff approach [6] of parameterising the pomeron flux within the proton. DPEMC also sets the default value of $\mathcal{S}^2$ to 0.03 at the LHC. EDDE uses an improved Regge-eikonal approach [7] to calculate the soft proton vertices and includes a Sudakov suppression factor to prohibit real gluon emission. There is no explicit soft-survival factor present in EDDE: it is assumed that the Regge parameterisation includes the effect of additional interactions between the proton lines. For further details of the calculations underlying both DPEMC and ExHuME please refer to [8].

The connection between the parton level process and the hadronic final state is not the same in the three Monte Carlos. Both ExHuME and EDDE are linked to Pythia [9, 10] for final state parton showering and hadronisation. DPEMC however, overrides the HERWIG [11] internal $\gamma\gamma$ interactions in e^+e^- collisions to simulate double pomeron exchange.

The processes available are similar in each Monte Carlo. Perhaps the most interesting is Higgs boson production with all subsequent decays. In addition, di-jet production is included in all three generators. None of the Monte Carlos yet includes the next-to-leading order 3 jet process, which could be an important, or even the dominant, background to the central exclusive $H \to b\bar{b}$ search channel.

Finally, inclusive double pomeron exchange (shown in figure 1(b)) will also act as a backgound to the exclusive process as there are 2 protons in the final state. These processes are always accompanied by pomeron remnants in the central system and it may be a challenge experimentally to separate these from the system of interest. Two models for these processes are the Cox-Forshaw model (CF), implemented in POMWIG [12], and the Boonekamp-Peschanski-Royon model (BPR) [13] that is included in DPEMC.

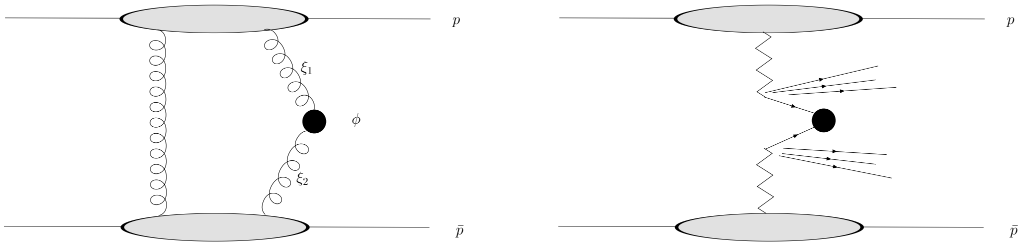

Fig. 1: The exclusive production process (a) and the inclusive (double pomeron) production process (b).

2 Results

Unless otherwise stated, all plots shown here were produced by using each of the Monte Carlos as they are distributed. constant soft survival factor, $\mathcal{S}^2$, of 0.03 was used in all three generators. In the case of ExHuME, where a parton distribution set must be chosen, the default is the 2002 MRST set, usually supplied via the LHAPDF library.

Using the default settings at the LHC energy of 14 TeV the total cross sections for production of a 120 GeV Higgs boson are 3.0 fb, 1.94 fb and 2.8 fb for DPEMC, EDDE and ExHuME respectively. However, despite these similar cross section predictions, the physics reach of the central exclusive process is predicted to differ significantly between the Monte Carlos. Figure 2(a) shows that ExHuME and EDDE predict that the cross section for exclusive Higgs boson production will fall much faster than DPEMC with an increase in Higgs boson mass. This is a direct effect of the Sudakov suppression factors growing as the available phase space for gluon emission increases with the mass of the central system. The different gluon momentum fraction, ξ, dependences lead to the differences in figure 2(b). With a fixed central mass an increase in collision energy is identical to a decrease in ξ, and the flatter ξ distributions of DPEMC and EDDE are reflected in the flatter $\sqrt{s}$ dependence compared to ExHuME.

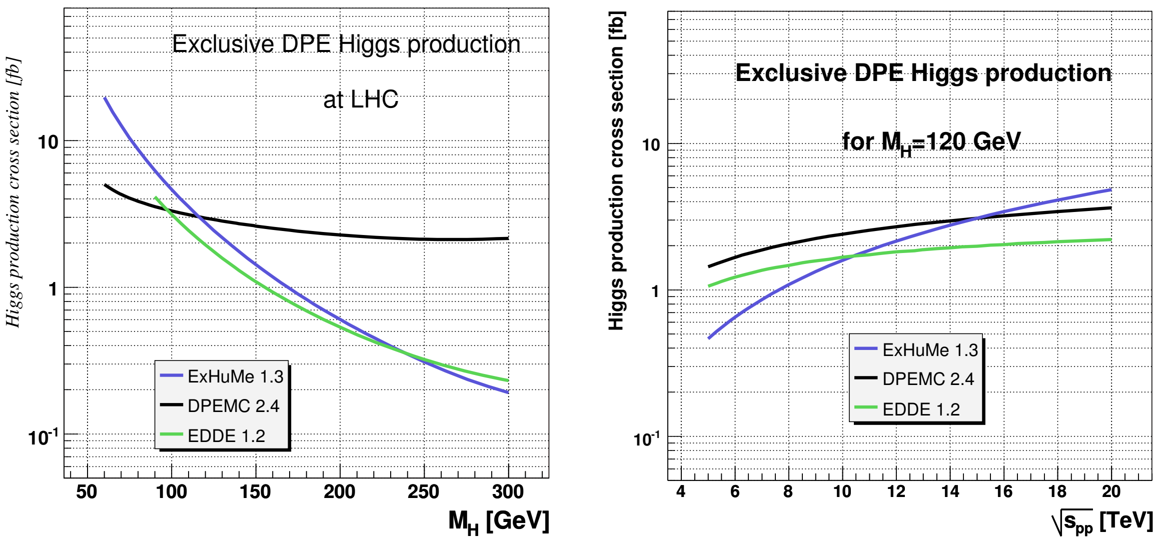

Fig. 2: (a) The left hand plot shows the higgs cross section as a function of higgs mass. (b) The right hand plot shows the increase in cross section with the collision energy (fixed gap survival factor).

The physics potential is dependent not only on the total cross section, but also on the rapidity distribution of the central system, which is shown in figure 3(b) together with the ξ distribution for the gluons. The more central rapidity distribution of ExHuME is due to the gluon distributions falling more sharply than the pomeron parameterisation present in DPEMC.

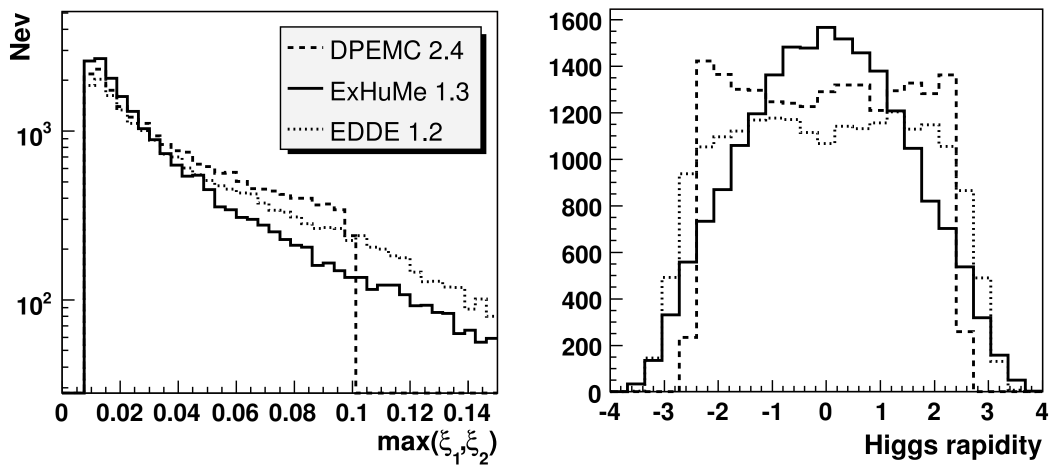

Fig. 3: The $max(\xi_1, \xi_2)$(a) and rapidity(b) of the 120 GeV Higgs. ExHuME predicts a steeper fall off in the number of events at high ξ and hence favours a less broad rapidity distribution compared to the soft non-perturbative models. Note that a cut is applied in DPEMC at $\xi = 0.1$, as required by the Bialas-Landshoff approach.

The acceptances of any forward proton taggers that might be installed at the LHC are sensitive to the rapidity distributions of the central system. The differences seen in figure 3(b) are reflected in different acceptance curves shown in figure 4. The predicted acceptances using taggers at 420 and 220 metres 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 forward taggers based on a detailed simulation of the detectors [14]. As seen in figure 4, as the mass of the central system increases the combined acceptance using detectors at *both* 220 and 420 metres 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). For a Higgs boson of mass 120 GeV the acceptances are predicted to be 46, 50 and 57% for EDDE, DPEMC and ExHuME respectively.

Changes from the default generator settings can have an effect on all of these distributions. As an example Fig. 5(a) shows the rapidity distribution from ExHuME using the CTEQ6M set compared to the MRST 2002 set of parton distribution functions. The CTEQ pdf has a flatter ξ dependence in the sensitive region of $Q_\perp \simeq 3$ GeV, which leads to a broader peak and sharper fall in the rapidity distribution and a larger cross section of 3.75 fb. This in turn should improve the efficiency of the forward proton taggers because not only are there more events, but there are more events at low rapidity. It is also possible to change the DPEMC code to add a harder ξ dependence of the form $(1-\xi)^\alpha$ to the pomeron flux parameterisation. This would favour a more central rapidity distribution, thus increasing the acceptance in the forward pots.

In di-jet production the di-jet mass fraction, R_{jj} is defined as $R_{jj} = M_{jj}/\sqrt{\hat{s}}$, where M_{jj} is the mass of the di-jet system and $\sqrt{\hat{s}}$ is the total invariant mass of the central system. R_{jj} should be large in a central exclusive event. In current searches for central exclusive di-jet production at the Tevatron [15], the CDF collaboration have experimentally defined exclusive events to be those where $R_{jj} > 0.8$. It should be noted that M_{jj} depends on the particular jet reconstruction algorithm used and the $\sqrt{\hat{s}}$ measurement is dependent either on tagging the outgoing protons or on reconstructing the missing mass using the calorimeter. In figure 6(a) we show the prediction for the R_{jj} fraction in exclusive events at the LHC, whilst in figure 6(b) we show two examples of the inclusive background with pomeron remnants from Pomwig and DPEMC. It is clear that the $R_{jj} > 0.8$ definition for central exclusive production leads to an overlap between the exclusive and inclusive regions for all of the Monte Carlo predictions.

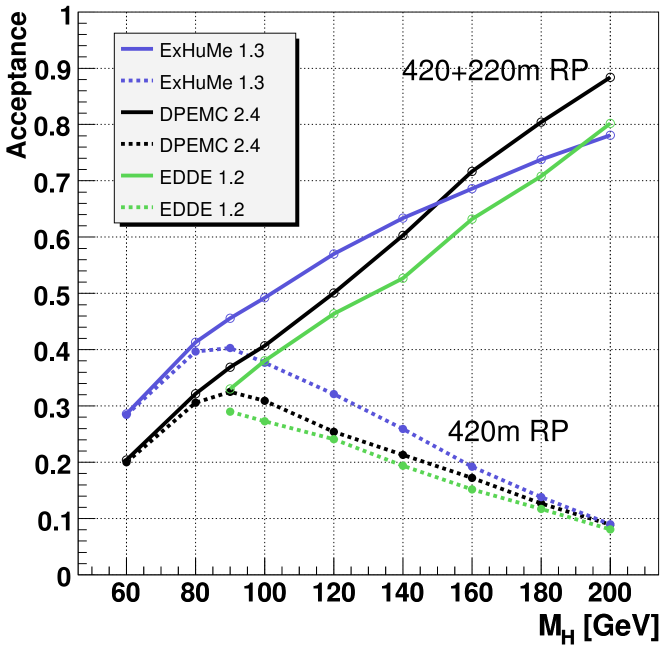

Fig. 4: The predicted acceptances for the proposed forward taggers at 420 metres and for a combination of taggers at 220 and 420 metres from the central detector.

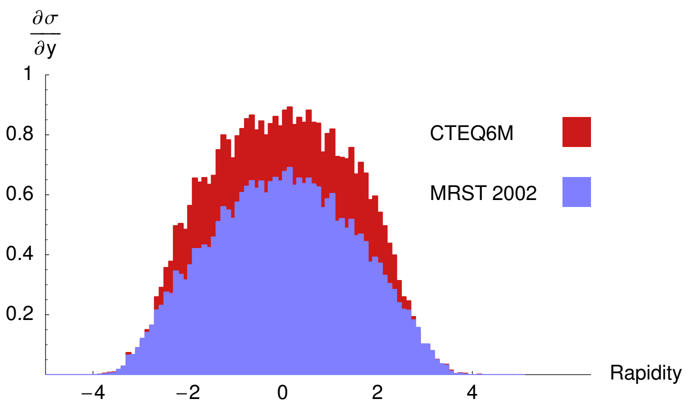

Fig. 5: The ExHuME rapidity distributions for production of a 120 GeV Higgs using MRST 2002 pdfs and the CTEQ6M pdfs.

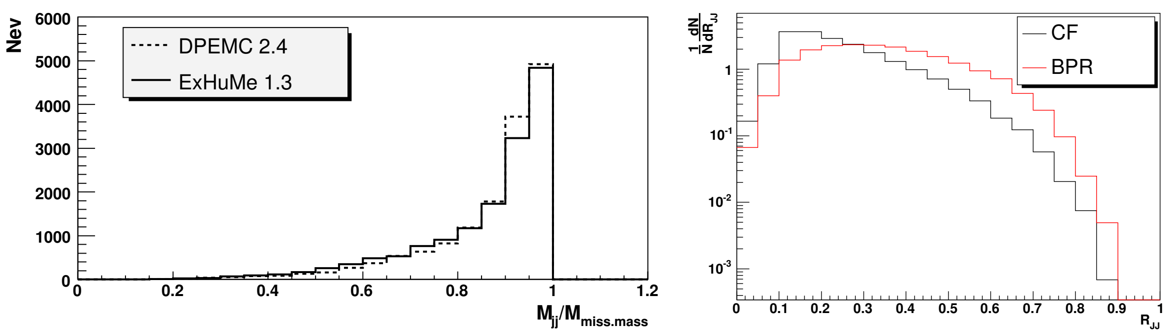

Fig. 6: R_{jj} distributions for (a) exclusive di-jet production using DPEMC and ExHuME and (b) the background inclusive di-jet production as predicted by the Cox-Forshaw (CF) and Boonekamp-Peschanski-Royon (BPR) models.

3 Summary

At a Higgs boson mass of 120GeV, all three Monte Carlo simulations give similar predictions for the cross section. However, the physics potential decreases for models that include Sudakov suppression, which will limit Higgs boson searches. The differing rapidity distributions of the central system result in different efficiencies for a forward proton tagging programme. In order to fully study the background to the $H \to b\bar{b}$ channel, future additions to the Monte Carlo programs should include the next to leading order three jet process.

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