DPEMC : A Monte-Carlo for Double Diffraction

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Abstract

We extend the `POMWIG` Monte Carlo generator developed by B. Cox and J. Forshaw, to include new models of central production through inclusive and exclusive Double Pomeron Exchange in proton-proton collisions. Double photon Exchange processes are described as well, both in proton-proton and heavy-ion collisions. In all contexts, various models have been implemented, allowing for comparisons and uncertainty evaluation and enabling detailed experimental simulations.

Program summary

Title of the program: DPEMC, version 2.3

Computer: any computer with the FORTRAN 77 compiler under the UNIX or Linux operating systems.

Operating system: UNIX; Linux versions 7.x, 8.x

Programming language used: FORTRAN 77

High speed storage required: < 25 MB

Keywords: Proton-(anti)proton collisions, diffraction, double pomeron exchange, double photon exchange.

Nature of the physical problem: Proton diffraction at hadron colliders can manifest itself in many forms, and a variety of models exist that attempt to describe it [1, 2, 3, 4, 5]. This program implements some of the more significant ones, enabling the simulation of central particle production through color singlet exchange between interacting protons or antiprotons.

Method of solution: The Monte-Carlo method is used to simulate all elementary $2 \rightarrow 2$ and $2 \rightarrow 1$ processes available in HERWIG. The color singlet exchages implemented in DPEMC are implemented as functions reweighting the photon flux already present in HERWIG.

Restriction on the complexity of the problem: The program relying extensively on HERWIG, the limitations are the same as in [8].

Typical running time: Approximate times on a 800 MHz Pentium III : 5-20 minutes per 10000 unweighted events, depending on the process under consideration.

1 Introduction

Doubly diffractive Higgs boson production has been much debated during the last decade, in a variety of theoretical approaches and predictions [1, 2, 3, 4, 5]. Now that the Tevatron is running, with both the D0 and CDF experiments well equipped for forward proton detection, there is good hope to clarify the situation in the mid-term. Meanwhile, potential upgrades of the LHC experiments ATLAS and CMS are being discussed, and a systematic evaluation of the DPE physics potential becomes necessary. The present work is meant as a step in this direction.

Available programs for diffraction simulation are `POMPYT` [6] and `RAPGAP` [7]; the factorized model of Cox and Forshaw, `POMWIG` [4]; and the Soft Color Interaction model of Enberg, Ingelman and Timneanu [3]. `POMWIG` is implemented as an extension to `HERWIG` [8] and relies on the following branchings:

$$p \to p' + \text{IP}, \quad \text{followed by} \quad \text{IP} \to q + X \tag{1}$$

where p and p' are the incoming and outgoing protons, the Pomeron is denoted IP, and q is the parton (quark or gluon) involved in the hard subprocess. In this *inclusive* picture, the final state can be made in lowest order of e.g. jets, photon pairs, lepton pairs, or a Higgs boson, accompanied by remnants from the IPIP collision and the outgoing protons.

Technically, the simulation of $\gamma\gamma$ interactions in ee collisions, provided by `HERWIG`, is transformed into pp induced IPIP interactions through a reweighting of the photon flux and a proper choice of the structure functions. The original implementation of this procedure, `POMWIG`, was based on a Regge fit to the Pomeron flux and Pomeron parton distribution functions provided by the H1 experiment [9].

Note that nothing prevents us from applying the same machinery to simulate *exclusive* IPIP interactions, i.e. processes where the entire IPIP center-of-mass energy is used in the production of a heavy central system. Most often, the Pomeron is seen as a gluonic object, so that the branchings

$$p \to p' + \text{IP}, \quad \text{followed by} \quad \text{IP} \to g + g_{NP} \tag{2}$$

result in a hard gluon-gluon interaction, with e.g. jet pairs, photon pairs or Higgs bosons in the final state. The color screening soft gluon, g_{NP}, couples to its counterpart from the opposite beam. Pomeron remnants are absent, and the protons again leave intact. Contrarily to the inclusive processes, which are being measured at the Tevatron (through dijet production [10]), the exclusive DPE has not yet been observed. This category of events is most appealing however, because Higgs boson production through this channel provides a very competitive measurement of its mass [11], and possible determination of its spin and parity, which is a major challenge in non-diffractive channels.

It is also simple to describe $\gamma\gamma$ interactions in the same framework : this is just going back to the original `HERWIG` where, to accommodate proton- or heavy ion-induced photon fluxes, we need to take into account the corresponding form factors. Compared to ee induced $\gamma\gamma$ interactions, an additional complication comes from the fact that one needs to simultaneously forbid strong interactions between the nuclei. To achieve this, one generally works in impact parameter space
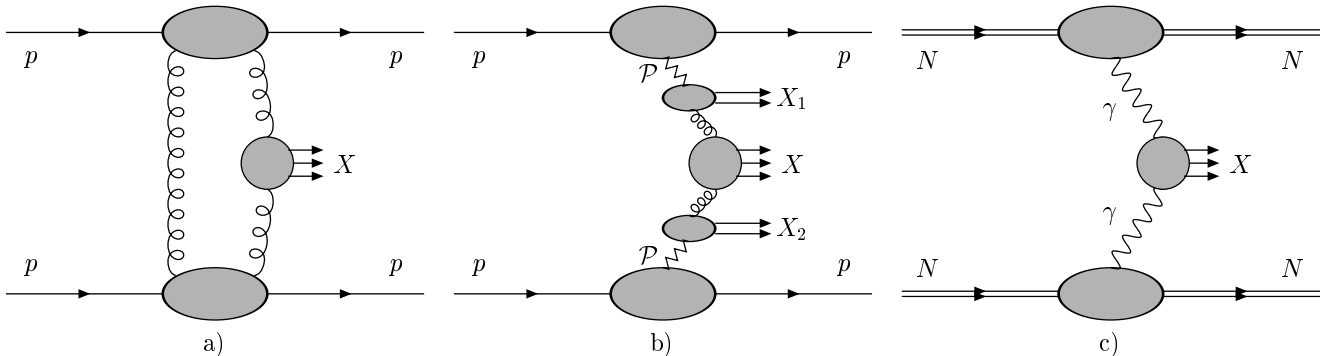
Figure 1: a) Exclusive QCD, b) Inclusive QCD and c) QED mediated diffractive reaction in pp or Heavy-Ion collisions.

and requires this impact parameter to be large enough for the nuclei not to geometrically overlap. These interactions have interest in their own right (they are a basic ingredient of the study of ultra-peripheral heavy-ion collisions, for example), but also provide a natural lower bound on the exclusive central production in pp collisions. In the worst case, these channels thus provide a conservative estimate of the physics potential of DPE.

This flexible framework allows to implement a number of models alternative to that of Cox and Forshaw in an analogous way. We focus here on the exclusive model of Bialas and Landshoff (BL) [1], and on its inclusive extension by Boonekamp, Peschanski and Royon (BPR) [2]. On the $\gamma\gamma$ side, we propose an implementation of the computations by Cahn and Jackson (CJ) [12], Drees, Ellis and Zeppenfeld (DEZ) [13], Papageorgiu [14], and Budnev et al [15].

We can unfortunately not pretend to be exhaustive, and the implementation of further models is left for future work. One notable example is the model of Khoze, Martin and Ryskin [5]. We also escape discussing proton non-survival through soft parton rescattering; the cross-sections presented here should thus be understood as incomplete in that respect. Note however that the results of the inclusive DPE models can be rescaled to the measured DPE dijet cross-section, as in [2]. On the other hand, in QED mediated diffraction, the proton collisions occur at much higher impact parameter, and the probability of parton rescattering is small [5].

The next section gives an overview of the models newly implemented (we leave most physical discussions aside and orient the reader to the references quoted above). Some results are then given in the third section, and the Appendix provides a guide to the package, and lists all settings and switches that control the output.

2   DPE models implemented in DPEMC

This section describes the new models and processes which can be studied using DPEMC. The model of Cox and Forshaw is described in [4] and of course still available.

Central system	Partonic process
Higgs bosons	$gg \to H$
Dijets	$gg \to gg,\ gg \to qq$
Photon pairs	$gg \to \gamma\gamma$

Table 1: Hard subprocesses relevant to exclusive DPE.

2.1 Exclusive DPE in the Bialas-Landshoff model [1]

The production cross section for a heavy system X (such as a Higgs boson, a jet pair, or a photon pair) in exclusive DPE collisions:

$$p + p \to p + X + p, \tag{3}$$

as illustrated in Fig. 1a, takes the form [1, 2]:

$$d\sigma^{(\text{exc})} = \int d\xi_1 d\xi_2\ F_{\mathbb{P}/p}(\xi_1) F_{\mathbb{P}/p}(\xi_2)\ d\hat{\sigma}(gg \to X). \tag{4}$$

The convolution in Eq. (4) is over the momentum fractions of the initial protons, ξ_1 and ξ_2, carried away by the Pomerons. The ux of the Pomeron inside the proton is parametrized as:

$$F_{\mathbb{P}/p}(\xi) = \mathcal{N} \int dv^2\ \frac{e^{\beta v^2}}{\xi^{2\alpha_\mathbb{P}(v^2)-1}}, \tag{5}$$

where v^2 is related to the momentum transfer squared and the proton momentum loss through $v^2 = t/(1 - \xi)$. Here the parameters $\mathcal{N}^2 = 288/\pi^5$, $\beta = 4\,\text{GeV}^{-2}$ and the Regge trajectory

$$\alpha_\mathbb{P}(t) = \alpha_\mathbb{P}(0) + \alpha'_\mathbb{P} t, \tag{6}$$

with intercept $\alpha_\mathbb{P}(0) = 1.08$ and slope $\alpha'_\mathbb{P} = 0.25\,\text{GeV}^{-2}$, are taken as in the original Bialas-Landsho model, Ref. [1].

The partonic cross section $d\hat{\sigma}$ in Eq. (4) describes the possible hard subprocesses $gg \to X$, of which a list is given in Table 1. In this context, the cross-sections satisfy color and angular momentum selection rules; namely the initial state is color singlet, and only the helicity con guration with $J_z = 0$ and $P = +1$ contributes to $\hat{\sigma}$ [16]. These features have important consequences on the sensitivity to Higgs boson searches, since they imply important suppression of the backgrounds while being harmless to a naturally scalar and color-singlet signal.

Note that properly speaking, the Bialas-Landsho expressions have been derived for Higgs bosons and massive quarks only. We propose here a generalization to gluon pair production, by using the corresponding color-singlet, $J_z = 0$ subprocess cross-sections instead of the original ones.

2.2 Inclusive DPE [2]

We implement the model of BPR as an alternative to that of Cox and Forshaw (CF) [4]. Although di erent in spirit, both lead to similar expressions and nal states. The production cross-section

Central system	Partonic process
Higgs bosons	$gg, qq \to H$
Dijets	$gg \to gg(qq),\ qg \to qg,\ qq \to gg(qq),\ qq' \to qq'$
Photon pairs	$gg \to \gamma\gamma,\ qq \to \gamma\gamma$
Lepton pairs	$qq \to ll$

Table 2: Hard subprocesses relevant to inclusive DPE.

for a system X (X = Higgs, Dijet, Diphoton, Dilepton) in inclusive DPE collision (see Fig. 1b):

$$p + p \to p + X + p + \text{Pomeron remnants}, \qquad (7)$$

can be expressed as follows [2]:

$$d\sigma^{(\text{inc})} = \sum_{i,j} \int dx_1 dx_2 \, d\xi_1 d\xi_2 \, F_{\mathbb{P}/p}(\xi_1) F_{\mathbb{P}/p}(\xi_2) \, f_{i/\mathbb{P}}(x_1, \mu^2) f_{j/\mathbb{P}}(x_2, \mu^2) \, d\hat{\sigma}(ij \to X). \qquad (8)$$

Besides the convolution over the proton momentum fractions, the integration runs over the Pomeron parton distribution functions. The Pomerons momentum fractions carried by the colliding partons are denoted x_1 and x_2. The proton induced Pomeron ux, $F_{\mathbb{P}/p}(\xi_i)$, is the same as in the exclusive case (the normalization and the parameters β, $\alpha_{\mathbb{P}}(0)$ and $\alpha'_{\mathbb{P}}$ are assumed identical to those used in [1]). The partonic content of the Pomeron is expressed in terms of distribution functions:

$$f_{i/\mathbb{P}}(x_i, \mu^2) = x_i \, G_{i/\mathbb{P}}(x_i, \mu^2), \qquad (9)$$

where $G_{i/\mathbb{P}}(x_i, \mu^2)$ are the \true densities" of the partons inside the Pomeron as measured by the H1 collaboration [9]. They are evaluated at a scale μ^2 given by the mass of the central system. The integral of $f_{i/\mathbb{P}}(x_i, \mu^2)$ is normalized to 1, so that in the limit $f_{i/\mathbb{P}}(x_i, \mu^2) \to \delta(x_i)$ the exclusive expressions are recovered.

Note that the cross-sections obtained in this way are rescaled in [2] according to the double di ractive dijet cross-section measured in [10]; this is not done in the program.

Some of the possible hard subprocesses $gg, qq \to X$ are listed in Table 2.

2.3   Two-photon reactions in pp and heavy-ion collisions [12, 13, 14, 15]

The production cross section for a central system X in heavy-ion collisions through double photon exchange (see Fig. 1c):

$$N + N \to N + X + N, \qquad (10)$$

can be approximated by a factorized form:

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Central system	Partonic process
Higgs	$\gamma\gamma \to H$
Dijet	$\gamma\gamma \to qq$
Lepton pairs	$\gamma\gamma \to ll$
Photon pairs	$\gamma\gamma \to \gamma\gamma$

Table 3: Hard subprocesses occurring in double photon exchange.

$$d\sigma^{(\gamma\gamma)} = \int d\xi_1 d\xi_2 \, F_{\gamma/\mathrm{N}}(\xi_1) F_{\gamma/\mathrm{N}}(\xi_2) \, d\hat\sigma(\gamma\gamma \to X). \tag{11}$$

The photon flux from an ion of electrical charge Z and mass M_N is parametrized as follows by DEZ [13]:

$$F_{\gamma/N}(\xi) = \frac{\alpha Z^2}{\pi} \frac{1}{\xi} \left[e^{-\xi^2 M_N^2/Q_0^2} + \left(1 + \frac{\xi^2 M_N^2}{Q_0^2} \right) \mathsf{Ei}(\xi^2 M_N^2/Q_0^2) \right], \tag{12}$$

where the momentum transfer scale $Q_0 \simeq 60\,\mathrm{MeV}$ and $\mathsf{Ei}(x) = \int_x^\infty \mathrm{d}t \, e^{-t}/t$. Formula (12) is valid for heavy nuclei only. An alternative formulation, derived in impact parameter space, yields [12, 14]:

$$F_{\gamma/N}(\xi, \xi_0) = \frac{2\alpha Z^2}{\pi\xi} \left[\frac{\xi}{\xi_0} K_0 \left(\frac{\xi}{\xi_0} \right) K_1 \left(\frac{\xi}{\xi_0} \right) - \frac{1}{2} \left(\frac{\xi}{\xi_0} \right)^2 \left(K_1^2 \left(\frac{\xi}{\xi_0} \right) - K_0^2 \left(\frac{\xi}{\xi_0} \right) \right) \right]. \tag{13}$$

In Eq. (13), $K_{0,1}(\xi/\xi_0)$ are the Bessel functions, while $\xi_0 \equiv 1/(RM_N)$ with R the radius of the ion. As discussed in the Introduction, this parameter appears because the impact parameter space integration is limited to the region where the colliding nuclei do not geometrically overlap. One can use $R \sim 1.2A^{1/3}$ for collisions of ions of atomic number A, or the proton radius to estimate the $\gamma\gamma$ cross-sections in proton-proton collisions. The partonic cross sections relevant in this context are listed in Table 3.

3   Results and Perspectives

All implemented fluxes are displayed in Figure 2. Apart from normalization, the CF and BL Pomeron fluxes differ mainly because of different choices of the Pomeron intercepts ($\alpha_{\mathbb{P}}(0) = 1.2$ is taken by CF, while $\alpha_{\mathbb{P}}(0) = 1.08$ is used by BL and BPR). The nucleus induced photon flux is illustrated for the proton ($f_{\gamma/p}$), Calcium ($f_{\gamma/Ca}$), and Lead ($f_{\gamma/Pb}$).

Figure 3 illustrates Higgs boson production cross-sections in various models, namely the inclusive models of CF and BPR, the exclusive cross-section by BL, and the photon-mediated cross-section by Papageorgiu. Figure 4 displays the \background" in the BPR model (the total and bb cross-sections are displayed) and in the exclusive BL model. The exclusive bb prediction
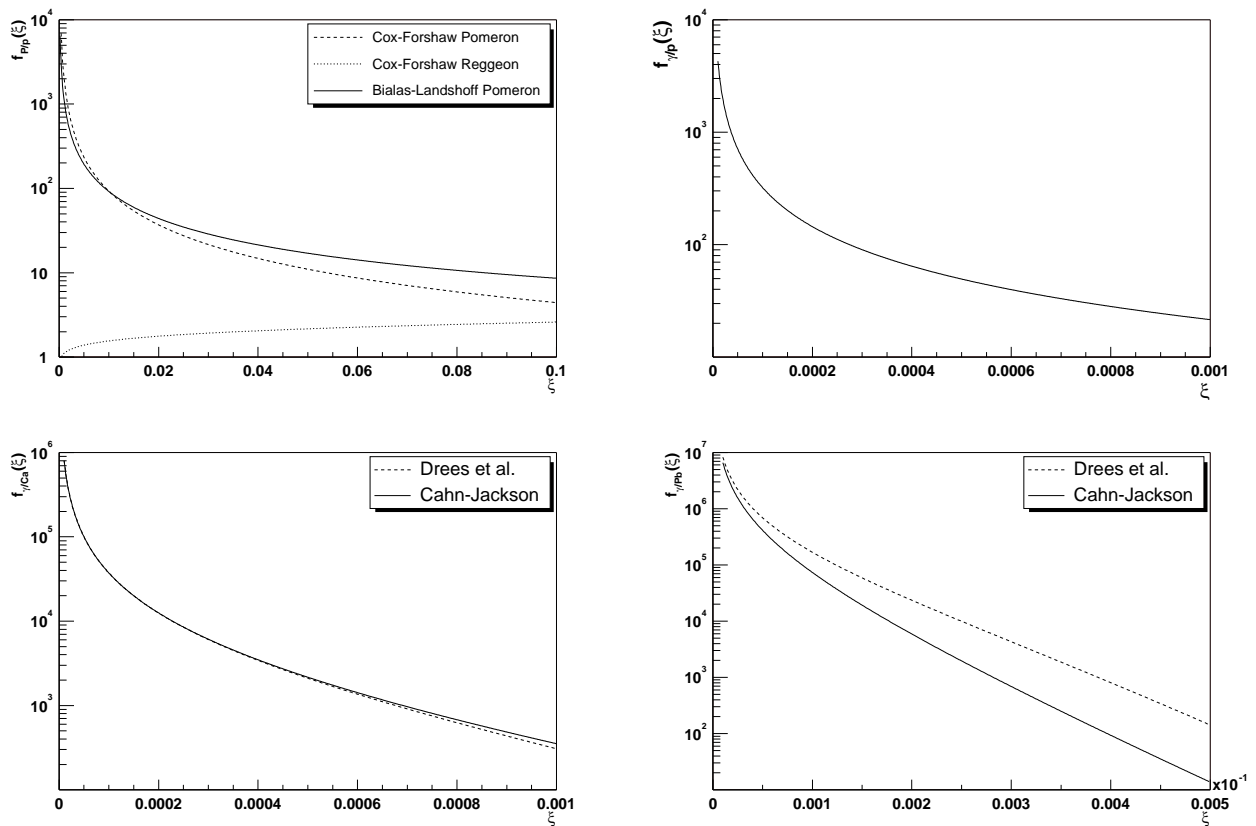
Figure 2: Beam induced uxes implemented in the program. *Upper left* : Pomeron ux according to [4] and [1, 2], and the Reggeon ux of [4]. *Upper right* : proton induced photon ux according to [12] and [14]. *Lower left and right* : Calcium and Lead induced photon ux following [12] and [13].

is much suppressed as expected, and is more distributed towards small angles than its inclusive counterpart.

Considering the above examples and others that can be worked in an analogous way, it is possible using this program to perform complete studies of experimental sensitivity to di ractively produced Higgs bosons. These studies can be done following models of inclusive or exclusive double Pomeron exchange, and of double photon exchange in proton or heavy ion collisions. Supersymmetric enhancements of the quark and gluon couplings to the Higgs boson can also be included as in `HERWIG`.

The implementation of further models of hard di raction, such as that of Ref. [5], will follow in subsequent versions of the program. Another important addition will be the inclusion of di ractive proton dissociation. Finally, since the beam particles currently need to be de ned as electrons, it is impossible to simulate soft underlying events or multiple parton interactions. This shortcoming will also be handled in the near future.

In summary, the aim of this work is not to promote one model or the other, but to provide a
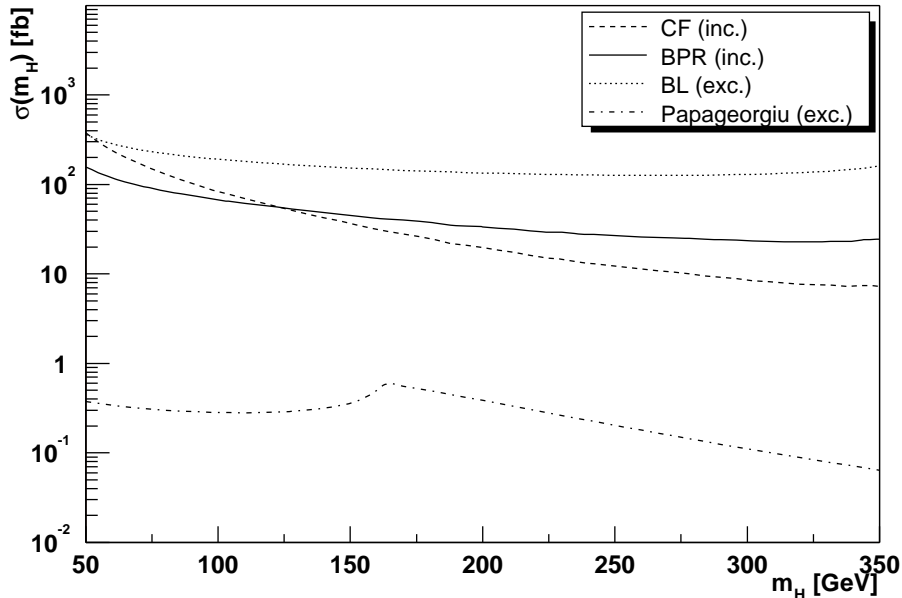
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Figure 3: Inclusive Higgs boson production cross-sections following CF [4] and BPR [2]. The exclusive predictions of BL [1] and Papageorgiu [14] are also illustrated.

tool that should allow to determine those that are compatible with the available and forthcoming data, and to prepare the analyses and constrain the predictions for the LHC.

4 Acknowledgments

A Manual

The source code for the program can be obtained from the authors or from Ref. [17], and includes an example main program. Some aspects of the implementation of `DPEMC` are described in Appendix B; here we discuss how to run the program. The processes are controlled using the following ags:

- `IPROC,ID,IL` select the hard process as in `HERWIG`;

- `TYPEPR` controls how the hard cross-section is to be evaluated; inclusively (`TYPEPR='INC'`) or only the color-singlet $J_Z = 0$ amplitude (`TYPEPR='EXC'`);
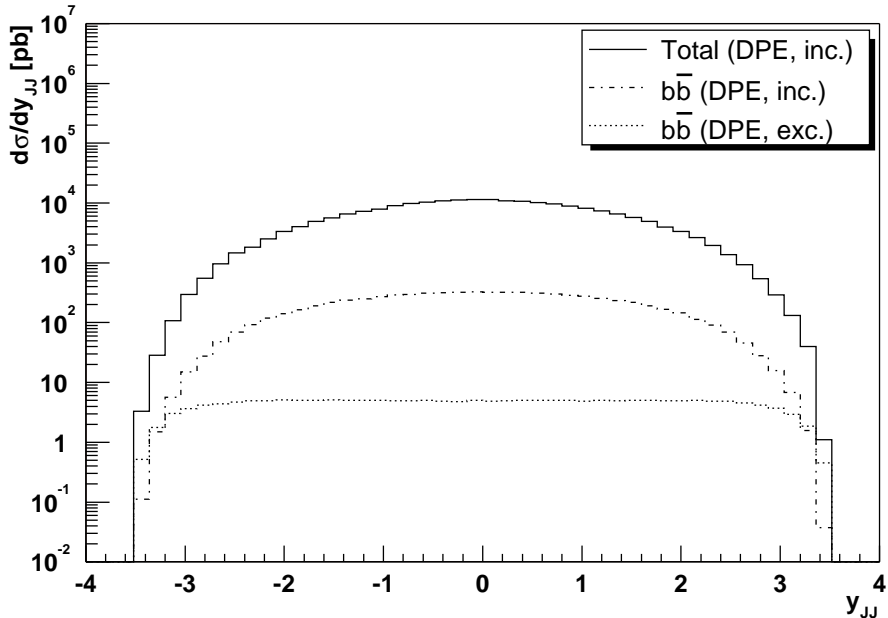
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Figure 4: Distributions of the average dijet rapidity ($y_{JJ} = (y_1 + y_2)/2$) in the inclusive model of BPR [2], compared to the exclusive model of BL [1]. The total inclusive dijet rate is displayed, as well as its bb component, to be compared to the exclusive bb cross-section.

- `TYPINT` switches between photon initiated processes (`TYPINT='QED'`), and gluon/quark initiated processes (`TYPINT='QCD'`);

- `NSTRU` controls the IP or γ ux; it can take values from 9 to 15, with meanings detailed in Table 4. For Pomeron uxes, it controls the parton density functions to be used as well;

- when `NSTRU=11`, `GAPSPR` and `CDFFAC` set the absolute cross-section normalizations. `GAPSPR` controls the gap survival probability for exclusive DPE processes (`TYPEPR='EXC'`); typical values are 0.1 at the Tevatron, and 0.03 at the LHC [5]. `CDFFAC` controls the normalization of inclusive DPE processes (`TYPEPR='INC'`), by comparison of the raw dijet computation to the measurement of [10]; the value 3.8 was found in [2].

- when appropriate, `AION` and `ZION` set the atomic and proton number of the colliding nuclei.

As in `POMWIG`, the beam particles need to be set as electrons in the main program, and the `HERWIG` facility generating $\gamma\gamma$ interactions is used and reweighted to the user's needs, depending on the above settings.

Since `NSTRU` controls which ux is to be used in the cross-section evaluations, the introduction of `TYPEPR` and `TYPINT` may seem somewhat redundant. This is however needed for technical reasons. First, exclusive IPIP interactions can not be treated as such since the gluon initiating the hard process carries the full momentum of its parent \beam particle", provoking errors in

NSTRU	Flux and structure functions
9	Factorized model, Pomeron flux [4]
10	Factorized model, Reggeon flux [4]
11	Bialas-Landshoff Pomeron flux [1, 2]
12	QED flux from Cahn, Jackson [12]; $R \sim 1.2A^{1/3}$
13	QED flux from Drees et al., valid for heavy ions only [13]
14	QED flux in pp collisions, from Papageorgiu [14]
15	QED flux in pp collisions, from Budnev et al [15]

Table 4: Possible values of NSTRU and their meaning.

HERWIG. To circumvent this problem, we needed to modify a few HERWIG routines. For example, the routine evaluating $\gamma\gamma \to f\bar{f}$ has been modified so that it can compute the color-singlet, $J_Z = 0$ $gg \to q\bar{q}, gg$ cross-section, depending on the values of TYPINT and TYPEPR.

For example, to simulate $b\bar{b}$ production in the exclusive Bialas-Landshoff model, one thus needs to request $\gamma\gamma \to b\bar{b}$ via IPROC=16005, set TYPINT='QCD', TYPEPR='EXC' so that the color-singlet, $J_Z = 0$ $gg \to q\bar{q}$ cross-section is actually computed, and NSTRU=11 requesting the Bialas-Landshoff flux. An exhaustive list of consistent flag settings is given in Table 5. These settings need to be followed strictly, the program is producing unpredictable results otherwise[1].

It was also needed to provide some additional routines, for the computation of the $\gamma\gamma \to H$ and color-singlet, $J_Z = 0$ $gg \to \gamma\gamma$ cross-sections. For completeness, a computation of $\gamma\gamma \to \gamma\gamma$ is also provided. A list of the new IPROC values, and of ID settings specific to DPEMC is given in Table 7.

Finally, we provide an additional routine that corrects the event record after each event is finalized (remember that all events are recorded as ee induced $\gamma\gamma$ interactions). This is needed for readability, but also to enable correct experimental simulations. When called, this routine resets the beam particles as protons, the secondary photon "beams" can be redefined as Pomerons or Reggeons, depending on the value of NSTRU, and the particles initiating the hard process, always stored as photons when TYPEPR='EXC', are redefined as gluons when TYPINT='QCD'.

B Structure of the program

We give here a list of the FORTRAN files that come with DPEMC. They have been tested to comply with HERWIG version 6.5. The first set of files contain the original HERWIG routines, which needed modifications for our purpose:

herwig6500.f : the original source code of HERWIG; the routines HWSFUN, HWEGAM, HWEPRO and HWHQPM, superseded by the following files, are renamed to avoid conflicts;

hwsfun65.f : structure function evaluation;

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[1]We have tried to make the program detect unsound settings as much as possible.

Final state	IPROC	TYPINT/TYPEPR	ZION/AION	NSTRU
		Inclusive DPE:		
Higgs bosons	1600+ID	QCD/INC	-	9, 10, 11
Dijets	1500	QCD/INC	-	9, 10, 11
Lepton pairs	1350+IL	QCD/INC	-	9, 10, 11
Photon pairs	2200	QCD/INC	-	9, 10, 11
		Exclusive DPE:		
Higgs bosons	9900+ID	QCD/EXC	-	11
Dijets	6000+ID	QCD/EXC	-	11
Photon pairs	9800	QCD/EXC	-	11
		Double photon exchange:		
Higgs bosons	9900+ID	QED/EXC	Z/A ; 1/1	12 or 13 ; 14
Dijets	6000+ID	QED/EXC	Z/A ; 1/1	12 or 13 ; 14
Lepton pairs	6006+IL	QED/EXC	Z/A ; 1/1	12 or 13 ; 14
Photon pairs	9800	QED/EXC	Z/A ; 1/1	12 or 13 ; 14

Table 5: Processes available for simulation, and the corresponding settings. The values of IPROC, ID and IL are set as in HERWIG [8], except for the new settings detailed in the Table 7. The ags should be set in the main program, of which examples can be obtained with the source code.
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IPROC	ID/IL	Process
1600+ID	ID=1,...,6	$H \to qq$ (resp. d,u,s,c,b,t)
	ID=7,8,9	$H \to l^+l^-$ (resp. $e^+e^-,\mu^+\mu^-,\tau^+\tau^-$)
	ID=10,11	$H \to W^+W^-$, ZZ
	ID=99	All decay modes
1350+IL	IL=0	All leptons (incl. neutrinos)
	IL=1,...,6	resp. e,ν_e,μ,ν_μ,τ,ν_τ

Table 6: Reminder of the ID,IL settings for Higgs boson and lepton pair production in HERWIG.

IPROC	ID/IL	TYPINT	Process
6000+ID	ID=1,...,6	QED/QCD	$\gamma\gamma/gg \to qq$ (resp. d,u,s,c,b,t)
	ID=11	QCD	$gg \to qq$ (all flavours)
	ID=13	QCD	$gg \to gg + qq$ (all flavours)
	ID=7,8,9	QED	$\gamma\gamma \to l^+l^-$ (resp. $e^+e^-,\mu^+\mu^-,\tau^+\tau^-$)
9900+ID	as for IPROC=1600	QED/QCD	$\gamma\gamma/gg \to H$
9800	-	QED/QCD	$\gamma\gamma/gg \to \gamma\gamma$

Table 7: Special ID,TYPINT settings for IPROC=6000, and the new processes IPROC=9800 and 9900; together with TYPEPR='EXC', these return the color-singlet $J_Z = 0$ cross-sections.

`hwegam65.f` : chooses the flux and generates Pomeron or photon momentum fractions and virtualities;

`hwepro65.f` : decides on the hard process;

`hwhqpm65.f` : calculates the cross-section for $gg \rightarrow qq$, gg in the $J_z = 0$ mode, for $\gamma\gamma \rightarrow qq$, W^+W^-, l^+l^- as in the original implementation of `HERWIG`, and for $\gamma\gamma \rightarrow qq$ in the $J_z = 0$ mode.

The following files contain the new routines needed to run `DPEMC`:

`flux65.f` : implementation of the Pomeron and photon fluxes inside a proton or heavy ion;

`h1qcd.f` : parton distribution functions inside the Pomeron;

`pomstr.f` : user defined Pomeron structure function;

`hwhigp65.f` : calculates the cross sections for $gg \rightarrow H$ and $\gamma\gamma \rightarrow H$;

`hwhqpp.f` : evaluates the cross sections for $gg \rightarrow \gamma\gamma$ in the case of exclusive diphoton production and for $\gamma\gamma \rightarrow \gamma\gamma$ in the heavy-ion collisions;

`hwnorm.f` : calculates the normalization of parton distribution functions inside the Pomeron;

`hwfxer.f` : corrects the event record.

In addition to the above mentioned files, a file `vegas.f`, containing the program `VEGAS` [18] for numerical integration, is also needed to obtain the normalization of Pomeron parton distribution functions. The example main programs provided with the package use `HBOOK` for histogramming, and thus need to be linked against the CERN program library [19].

An example main program is in `example.f`, and produces 10000 exclusive cc events in the Bialas-Landshoff model. It is compiled by executing `gmake -f makeExample`.

C

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