# Forward Physics Monte Carlo

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**Abstract**

We give a short description of the Forward Physics Monte Carlo (FPMC) which is intended for studies of diffractive physics and two-photon exchanges at the LHC.

The Forward Physics Monte Carlo (FPMC) was developed to cover a variety of physics processes that can be detected with very forward proton spectrometers. The detectors are currently being proposed to ATLAS and CMS collaborations and soon will enable studies of single and double diffractive production, central exclusive production (CEP), two-photon exchange etc. Implementing all of these processes into a single FPMC program has the advantage of a quick data-to-model comparison and easier interfacing with the detector simulation framework. The latest version of the generator is available at `www.cern.ch/project-fpmc.`

In this report we shortly summarize the structure and usage of the FPMC program before presenting a few results coming directly from the generator.

## 1 The FPMC program

The FPMC is a stand-alone generator which generates events, treats particle decays and hadronization as in HERWIG. The forward physics processes are based on an exchange of pomerons, photons, or gluons in case of double pomeron exchange, two-photon production and central exclusive production, respectively. In FPMC, the radiation of a mediating particle of the incoming proton is described in terms of fluxes, probabilities that the incoming proton emits a mediating particle of a given energy. A selection of a specific flux therefore leads to a generation of a particular physics processes. In the following we briefly mention the most important switches of the program which are tabulated in Table 1. The detailed description of the program can be found in the complete manual [1].

- TYPEPR - switches between exclusive (“EXC”) and inclusive processes (“INC”), for example between the Higgs diffractive production in completely exclusive mode or in the inclusive one when there are pomeron remnants present.
- TYPINT - selects the QCD (“QCD”) or photon (“QED”) processes.
- NFLUX - as mentioned above, it specifies the mechanism of the exchange: 9 (factorized model, double pomeron exchange), 10 (factorized model, double reggeon exchange), 15 (two-photon exchange based Budnev photon flux [2]), 16 (exclusive KMR model, two gluon exchange [3]). Other non-default fluxes like Papageorgiou photon flux [4] or photon flux for heavy ions [5] are also present.

- IPROC - the process number, specifies what final state will be produced of the exchanged particles, some possible values are listed in Table 2. For illustration: IPROC=19999, NFLUX=16, TYPEPR="QCD" generates exclusive Higgs production with all decay channels open following the KMR prediction or IPROC=16010, NFLUX=15, TYPEPR="QED" produces exclusive $WW$ two-photon production.
- ISOFTM - with this parameter, the survival probability factor [6] can be turned on (1) and off (0). It is of the order of of 0.03 for LHC (0.1 for Tevatron) for QCD (double pomeron exchange, CEP) and 0.9 for QED two-photon exchange processes.
- IFITPDF - specifies a set of the parton density functions in the pomeron/reggeon. The common parameters are 10 or 20 which correspond to the most recent H1 and ZEUS fits of the densities, respectively [7].

| **Parameter** | **Description** | **Default** |
|---|---|---|
| TYPEPR | Select exclusive 'EXC' or inclusive 'INC' production | 'EXC' |
| TYPINT | Switch between QED and QCD process | 'QCD' |
| NFLUX | Select flux | 9 |
| IPROC | Type of process to generate | 11500 |
| MAXEV | Number of events to generate | 1000 |
| ISOFTM | Turn survival probability factor on (1), off(0) | 1 |
| ECMS | CMS energy (in GeV) | 14000 |
| HMASS | Higgs mass (GeV/$c^2$) | 115 |
| PTMIN | Minimum $p_T$ in hadronic jet production | 0 |
| YJMIN | Minimum jet rapidity | -6 |
| YJMAX | Maximum jet rapidity | +6 |
| EEMIN | Minimum dilepton mass in Drell-Yan | 10.0 |
| IFITPDF | Diffractive PDF | 10 |
| NTNAME | Output ntuple name | 'tmpntuple.ntp' |

Table 1: Main FPMC parameters.

## 2 Examples of processes produced in FPMC

### 2.1 Inclusive diffraction

The first example we discuss is the inclusive diffraction. The starting point to predict inclusive diffraction at the LHC (or the Tevatron) is the measurement of gluon and quark densities in the pomeron performed at HERA [7]. Once these parton densities are known, it is straightforward to compute the diffractive production at the Tevatron or the LHC. The only assumption is that the factorization breaking between $ep$ and hadron collisions is a soft process, independent of the hard process and it can be applied as a multiplicative factor to the cross section. In that sense, we call this model "factorized" model. In FPMC, we assume the survival probability to be 0.1 at the Tevatron and 0.03 for the LHC.

It will be important to remeasure the structure of the pomeron at the LHC and to study the factorization breaking of the cross section at high energies because inclusive diffraction also represents an important background for most of the processes to be studied at the LHC using forward detectors like exclusive Higgs production, studies of the photon anomalous coupling, SUSY particle production in two-photon exchange, etc.

In Figure 1, we give the dijet cross section as a function of minimum transverse jet momentum $p_T^{min}$ for inclusive dijets, light quark jets and b-jets only. These cross sections were obtained using the process numbers IPROC=11500, 11701 and 11705 for $gg$, light quark and $b$ jets processes, respectively. Other parameters were set NFLUX=9, TYPEPR='QCD', IFITPDF=10.

### 2.2 Central exclusive production / exclusive double pomeron exchange

In exclusive production, the full energy of the exchanged particles (pomerons, gluons) is used to produce a heavy object (Higgs boson, dijets, diphotons, etc.) in the central detector and no energy is lost in pomeron remnants as in inclusive case. There is an important kinematic consequence that the mass of the produced object can be computed using the proton momentum losses $\xi_1, \xi_2$ measured in the forward detectors as $M = \sqrt{\xi_1 \xi_2 s}$ (with $s$ being the total center of mass energy of colliding protons). We can benefit from the good forward detector resolution on $\xi$ to measure the mass of the produced object precisely. Moreover, since the CEP fulfill certain selection rules also other kinematic properties (spin and parity) of the produced object can be easily determined.

In Fig. 2 (left), we display the CEP cross sections of Higgs boson with its direct background of $b$-jet production as they are obtained directly from FPMC generator using the process numbers IPROC=19999 and 16005, respectively. Other parameters were set to NFLUX=16, TYPEPR='QCD'.

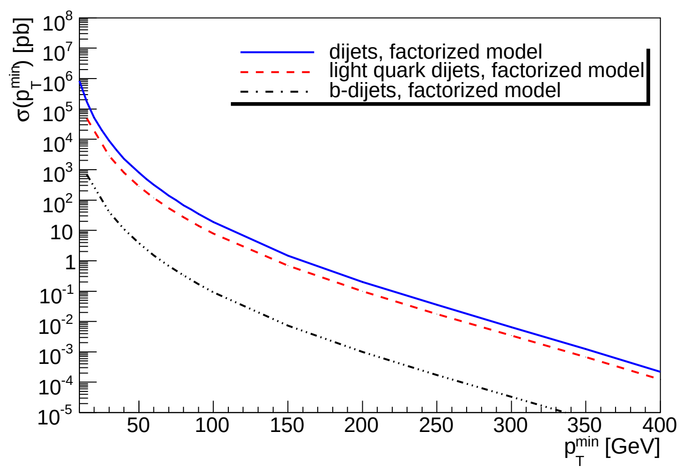


Fig. 1: Dijet cross section for inclusive dijets, light quark jets and b-jets only as a function of minimum transverse momentum of the two leading jets with $p_T^{jet1}, p_T^{jet2} > p_T^{min}$ at $\sqrt{s} = 14$ TeV.

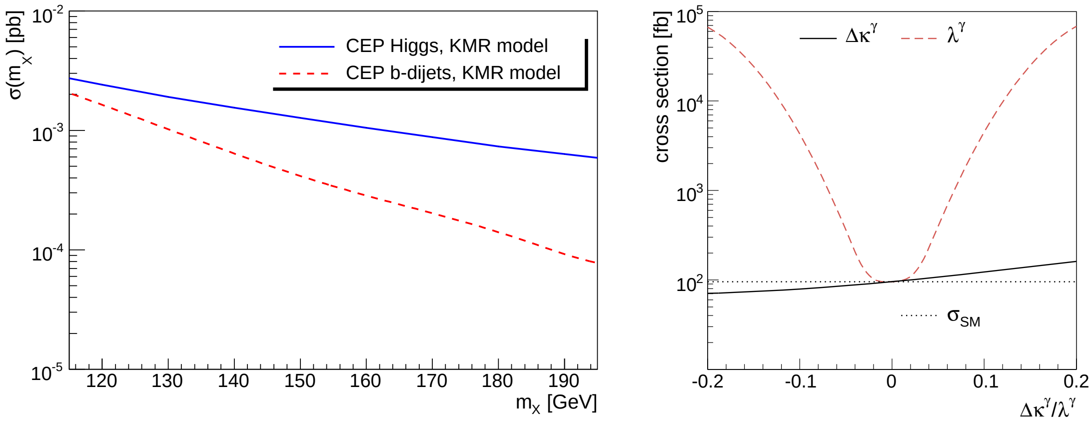


Fig. 2: *Left:* Higgs boson central exclusive production cross section for various masses of the Higgs boson $m_X$ and $b$-jet production cross section as a function of the $b\bar{b}$ invariant mass. *Right:* Cross section of the SM $WW$ production through two-photon exchange as well as the effect of the $\Delta\kappa^\gamma$ and $\lambda^\gamma$ anomalous parameters.

### 2.3 $WW$ two-photon production

The two-photon production is described in terms of the photon flux. In FPMC one can study the dilepton, diboson, diphoton, and Higgs production. In the following we will discuss as an example the $W$ pair production. The process number and other parameters for this process are IPROC=16010, TYPEPR='EXC', TYPINC='QED'.

Besides the SM production, FPMC was interfaced with O'Mega matrix element generator [8] to allow anomalous coupling studies [9]. Currently, the triple gauge boson $WW\gamma$ effective Lagrangian is included which is parametrized with two anomalous parameters $\Delta\kappa^\gamma$, $\lambda^\gamma$. The dependence of the total diboson production cross section in two-photon exchanges as a function of the two anomalous parameters is depicted in Fig. 2 on the right.

## 3 Conclusion

In this short report, we described the new Forward Physics Monte Carlo generator which allows to produce single and double pomeron exchanges, two-photon induced processes and Central Exclusive Production at hadron colliders. These processes are a heart of the forward physics program at the LHC. The main aim is to combine various available models into one interface to allow easy data-to-model comparisons.

## References

[1] M. Boonekamp, V. Juranek, O. Kepka, M. Rangel. C. Royon, to appear; see `http://cern.ch/project-fpmc/`

[2] V. M. Budnev, I. F. Ginzburg, G. V. Meledin and V. G. Serbo, Phys. Rept. **15** (1974) 181.

| Process | IPROC | TYPEPR | TYPINC | NFLUX |
|---|---|---|---|---|
| Incl. $H$ | 11600+ID | INC | QCD | 9,10,11 |
| Excl. $H$ | 19900+ID | EXC | QCD | 16 |
| Excl. $H$ | 19900+ID | EXC | QED | 12,13,14,15 |
| Incl. $q\bar{q}$ | 11500 | INC | QCD | 9,10,11 |
| Incl. $q\bar{q}$ | 11700+ID | INC | QCD | 9,10,11 |
| Excl. $q\bar{q}$ | 16000+ID | EXC | QCD | 16 |
| Incl. $W^+W^-$ | 12800 | INC | QCD | 9,10,11 |
| Excl. $W^+W^-$ | 16010 | EXC | QED | 15 |
| Incl. $\gamma\gamma$ | 12200 | INC | QCD | 9,10,11 |
| Excl. $\gamma\gamma$ | 19800 | INC | QCD | 16 |
| Excl. $\gamma\gamma$ | 19800 | EXC | QED | 12,13,14,15 |
| Excl. $ll$ | 16006+IL | EXC | QED | 12,13,14,15 |
| Incl. $ll$ | 11350+IL | INC | QCD | 9,10,11 |

Table 2: Setting of the FPMC for a number of physics processes. ID specif the decay products of a Higgs boson or a type of quarks produced. IL denote type of leptons in the final state. See manual for details [1].


[3] V.A. Khoze, A.D. Martin, M.G. Ryskin, Eur. Phys. J. **C19** (2001) 477; Eur. Phys. J. **C24** (2002) 581; arXiv:0802.0177; Phys. Lett. B650 (2007) 41; A.B. Kaidalov, V.A. Khoze, A.D. Martin, M.G. Ryskin, Eur. Phys. J. **C33** (2004) 261; Eur. Phys. J. **C31** (2003) 387

[4] E. Papageorgiu, Phys. Lett. B**250** (1990) 155 Phys. Lett. B **352** (1995) 394.

[5] M. Drees, J. Ellis, D. Zeppenfeld, Phys. Lett. **B223** (1989) 454.

[6] V. A. Khoze, A. D. Martin and M. G. Ryskin, Eur. Phys. J. C **23** (2002) 311.

[7] H1 Collaboration, Eur. Phys. J. C**48** (2006) 715;
C. Royon, L. Schoeffel, R. Peschanski, E. Sauvan, Nucl. Phys. B**746** (2006) 15;
C. Royon, L. Schoeffel, S. Sapeta, R. Peschanski, E. Sauvan, Nucl. Phys. B**781** (2007) 1.

[8] M. Moretti, T. Ohl and J. Reuter, arXiv:hep-ph/0102195.

[9] O. Kepka, C. Royon, arXiv:0808.0322, in press in Phys. Rev. D.