Monte Carlo Generator
EPJPSI
for J/ψ mesons
in high energy γp, ep, μp, $p\bar{p}$ and pp collisions

Hannes Jung

1 Tabular Summary

program name	EPJPSI
version	3.0
date of last version	Oct. 1993
author	Hannes Jung (F36HJU at DHHDESY3)
program size	$\sim$ 10000 lines of code
input files needed	altsti.dat
computer types	standard Fortran 77, run on IBM MVS, VAX
other programs called	JETSET 7.3
	DIVON 4 (CERN Library)
initial parton shower	optional
hard sub-processes included	$\gamma g \to J/\psi g$
	$\gamma \mathbb{P} \to \mathrm{J}/\psi$
	$\gamma \mathbb{P} \to \mathrm{J}/\psi \mathrm{X}$
	$\gamma g \to B\bar{B}(\to J/\psi X)$
	$\gamma g \to c\bar{c}J/\psi$
	$gg \to J/\psi \gamma$
	$gg \to J/\psi g$
	$gg \to J/\psi J/\psi$
	$q\bar{q} \to J/\psi J/\psi$
	$gg \to \chi(\to J/\psi \gamma) g$
	$qg \to \chi(\to J/\psi \gamma) q$
final parton shower	optional
fragmentation model	LUND string
initial QED radiation	none

2 Introduction

The program EPJPSI can be used to generate J/ψ mesons in $e\ p$, μp, γp, pp and $p\bar{p}$ collisions. The hadronisation is done with the LUND string fragmentation. The integration of the cross section and the event generation are done with the help of the DIVON package.

3 Physics and Monte Carlo implementation

3.1 Kinematics

The main kinematic relations for processes $A+B \to J/\psi+X$ with A, B being the beam particles and X describing the final state including all particles except the J/ψ are given here. Let P_1 (P_2) the momentum of the beam particle A (B) with mass $P_1^2 = M_1^2$ $(P_2^2 = M_2^2)$ and x_1 (x_2) the fractional momentum of the beam momentum carried by the parton p_1 (p_2). Then the following relations hold:

$$
\begin{aligned}
s &= (P_1 + P_2)^2 \simeq 2P_1.P_2 &(1)\\
\hat{s} &= (p_1 + p_2)^2 = (x_1 P_1 + x_2 P_2)^2 \simeq 2x_1 x_2 P_1.P_2 \simeq x_1 x_2 s &(2)
\end{aligned}
$$

where $p_1^2 = p_2^2 = 0$ and the "$\simeq$" sign indicates that the masses M_1, M_2 are neglected. In the Monte Carlo implementation we start by generating x_1, $_2$ according to the probability density of parton p_1 (p_2) in particle P_1 (P_2) approximated by a $1/x$ spectrum for reasons of efficiency.

In case of $p\bar{p}$ collisions the probability density of finding a gluon (quark) inside the proton (antiproton) is given by the structure functions $xG^p(x, \mu^2)$ $(xq_i^p(x, \mu^2)$ i = flavour index) with ^{p} indicating proton. In case of ep and μp collisions the probability of finding a photon with fractional momentum $x_1 = y$ and

$$y = \frac{P_2.p_\gamma}{P_2.P_1} \tag{3}$$

is given by the Equivalent Photon Approximation (EPA). In γp collisions we simply have $x_1 = y = 1$.

If the (virtual) photon is further resolved into partons (resolved photon) the photon spectrum is still given by EPA with $y = \frac{P_2 p_\gamma}{P_2 P_1}$, but now $x_1 = \frac{P_2 p_1}{P_2 P_1}$ is the fraction of the beam momentum carried by the parton p_1. Thus in direct photoproduction (where the photon interacts directly with a parton coming from the proton) we have $x_1 = y$ whereas in resolved photoproduction a parton inside the photon interacts with a parton from B. The probability denisty for partons inside the photon are given by $x_\gamma G^\gamma(x_\gamma, \mu^2)$ and $x_\gamma q_i^\gamma(x_\gamma, \mu^2)$ with $x_\gamma = \frac{x_1}{y}$. Thus having fixed the momenta of the interacting partons, the "hard" subprocess $p_1 + p_2 \to p_3 + p_4 + \cdots$ ($p_3^2 = m_3^2$, $p_4^2 = m_4^2$) is generated according to phase space and matrix element.

Kinematic arguments now lead to lower and upper limits on x_1:

$$x_{1\ max;min} = \frac{s + W_0{}^2 \pm \sqrt{(s - W_0{}^2)^2 - 4 M_1{}^2 W_0{}^2}}{2(s + M_1{}^2)} \tag{4}$$

with $W_0^2 = (m_3 + m_4 + \cdots + M_2)^2 - M_2^2$, and for x_2:

$$x_{2\ min} = \frac{(m_3 + m_4 + \cdots)^2}{x_1 s} \leq 1 \tag{5}$$

3.1.1 Equivalent Photon Approximation

In leptoproduction in general the cross section can be factorised into (virtual) photon density and the cross sections σ_L and σ_T for longitudinal and transverse polarised photons. Since the photon density falls off with $1/Q^2$ it is quite reasonable to deal here only with quasi real photons, i.e. neglecting the contribution of longitudinal photons. Thus we can write the leptoproduction cross section at low Q^2 as :

$$d\,\sigma_{lp \to l' X}(s) = \frac{dN}{dy\, dQ^2} \sigma_T(y\, s) \tag{6}$$

with $\frac{dN}{dy\, dQ^2}$ being the equivalent photon approximation and σ_T the photoproduction cross section for transverse photons at $Q^2 = 0$ and at a reduced CM energy of ys. The photon spectrum is given by:

$$\frac{dN}{dy\ dQ^2} = \frac{\alpha}{\pi} \left((1 - y - \frac{y^2}{2}) \frac{1}{y\ Q^2} - \frac{M_1 y}{Q^4} \right) \tag{7}$$

where the last term is a correction to the well known Weizsäcker Williams approximation when factors of the order of $\frac{M_1}{Q^2}$ are kept [1]. Lower and upper limits on Q^2 come from kinematic arguments:

$$Q^2_{min} = \frac{M_1^2 y^2}{(1-y)} \tag{8}$$

$$Q^2_{max} = ys - {W_0}^2 \tag{9}$$

One should note that with the formula given in eq.(7) the photon has a small virtuality $Q^2 = -q^2 = (l-l')^2$ thus leading to a nonvanishing scattering angle of the scattered lepton. With this virtuality given, the lower bound on x_2 in eq.(5) is changed to

$$x_{2\,min} = \frac{(m_3 + m_4 + \cdots)^2 + Q^2}{y\ s} < 1 \tag{10}$$

It has been checked for the case of open heavy quark electroproduction that the "Equivalent Photon Approximation" using eq.(7) and eq.(10) agrees within a few % with the complete calculation of $eg \to e'Q\bar{Q}$ [2] in all variables $y, Q^2, \hat{s}$ and in the total cross section.

3.1.2 Diffractive and Elastic Processes

Single diffractive processes are characterised by:

$$A + B \to X + B' \tag{11}$$

where B' is a low mass state ($m_{B'} \leq 3-5$ GeV) coming from particle B and X stands for the rest of the particles produced. Elastic processes are described by $A + B \to A + B$.

In J/ψ production the terminology elastic and diffractive comes from the Vector-Meson-Dominance model, where vectormesons are intermediate states of the photon. Thus in that picture the relevant process in γp scattering is the scattering of intermediate J/ψ mesons with the proton, leading to $J/\psi + p \to J/\psi + p$ for elastic and $J/\psi + p \to J/\psi + p'$ for diffractive production with p' being the low mass state ($m_{p'} \leq 3-5$ GeV). Even within QCD models for J/ψ production this terminology is kept.

The interaction between particle A and B in diffractive processes can be described by pomeron $\mathbb{P}$ exchange. The pomeron density inside a proton is given in [3] but here we include the parameter $\hat{\epsilon}$ responsible for the rising total cross section seen in $p\bar{p}$ and recently in γp [4, 5] scattering experiments. By $f_{p\mathbb{P}}(t,r)$ we denote the probability density that the proton (p) splits into a proton (p') and a Pomeron ($\mathbb{P}$) with momentum fraction r of the momentum of the incoming proton (p). This density depends on the momentum transfer $t=(p-p')^2$. $f_{p\mathbb{P}}(t,r)$ is then

$$f_{p\,\mathbb{P}}(t,r) = \frac{\beta^2_{p\mathbb{P}}(t)}{16\pi} r^{1-2\alpha_{\mathbb{P}}(t)} \quad , \tag{12}$$

where

$$\beta_{p\,\mathbb{P}}(t) = \beta_{p\,\mathbb{P}}(0) e^{(-\frac{1}{2}R_N^2|t|)} \quad ; \quad \alpha_{\mathbb{P}}(t) = \alpha_{\mathbb{P}}(0) + \alpha'_{\mathbb{P}} t + \hat{\epsilon} \quad ;$$

$$R_N^2 = 3.3 GeV^{-2} \; ; \; \beta_{p\,\mathbb{P}}(0) = 10 \text{ GeV}^{-1} \; ; \; \alpha_{\mathbb{P}}(0) = 1 \; ; \; \alpha'_{\mathbb{P}} = 0.25 \text{ GeV}^{-2} \; ; \; \hat{\epsilon} = 0.085. \tag{13}$$

The pomeron can be thought of being made by a gluon ladder. In such a picture it is then quite natural to assign a gluon (parton) density to the pomeron $\mathbb{P}$, but shape and normalisation of this density are a priori unknown. Here we account only for gluons with possible different distributions such as $xG_0(x) = 6x(1-x)$ when the Pomeron consists of two gluons or $xG_5(x) = 6(1-x)^5$ when the gluon is as soft as in the proton and intermediate ones with $xG_n(x) = (n+1)\,(1-x)^n$ with $1 \le n \le 5$.

3.2 Physics Subprocesses

In the following the processes that can be simulated are described. We start discussing J/ψ photoproduction (leptoproduction is very similar since $Q^2_\gamma \simeq 0$).

The general form of the cross section is:

$$\sigma = \int dx_1\, dQ_1^2\, dx_2 dQ_2^2 f_1(x_1, Q_1^2) \cdot f_2(x_2, Q_2^2) \hat{\sigma}$$

where $\hat{\sigma}$ is the cross section of the hard subprocess and $f_1(x_1, Q_1^2)$ is the parton density in beam particle A and $f_2(x_2, Q_2^2)$ is the parton density in beam particle B.

In the case of direct photoproduction $f_1(x_1, Q_1^2) = \delta(1 - x_1)$. When resolved photoproduction is considered f_1 just gives the parton density inside the photon. For leptoproduction $f_1(x_1, Q_1^2)$ is given by the equivalent photon spectrum eventually convoluted with the parton density of the photon in case of resolved photons. In all cases $f_2(x_2, Q_2^2)$ is given by the parton density of the proton.

pp or $p\bar{p}$ collisions are described in a similar way with the corresponding partons densities for f_1 and f_2.

3.2.1 Inelastic J/ψ production $\gamma g \to J/\psi g$

Inelastic J/ψ photoproduction can be described by the γg fusion mechanism. In the so called non-relativistic color singlet model [6] J/ψ production looks as follows:

$$\gamma g_1 \to c\bar{c}|_{p_c = p_{\bar{c}}} g \to J/\psi g_2$$

where $c\bar{c}_{p_c = p_{\bar{c}}}$ indicate that the intermediate charm quarks have the same momentum $p_c = p_{\bar{c}} = 1/2 p_{J/\psi}$ and $m_c = 1/2 m_{J/\psi}$. The coupling $c\bar{c} \to J/\psi$ is determined by the wavefunction of the J/ψ. This wave function is calculated from the measured leptonic decay width $\Gamma(J/\psi \to \ell^+\ell^-)$, including QCD corrections [7]:

$$\Gamma_{\ell\bar{\ell}} = \Gamma^0_{\ell\bar{\ell}} \, (1 - \frac{16}{3}\frac{\alpha_s}{\pi}) = 5.4 \mathrm{keV} \tag{14}$$

where the lowest order width $\Gamma^{(0)}_{\ell\bar{\ell}}$ is given by

$$\Gamma^{(0)}_{\ell\bar{\ell}} = 16\pi e_q^2 \alpha_{em}^2 \frac{|\psi(0)|^2}{m^2_{J/\psi}}. \tag{15}$$

Using $\Gamma_{\ell\bar{\ell}}$ instead of $\Gamma^{(0)}_{\ell\bar{\ell}}$ the total cross section is increased by a factor of ~ 2.

The cross section for the process $\gamma \, p \to J/\psi \, X$ now reads:

$$\sigma = \int dx \, d\hat{t} G(x) \frac{1}{16\pi \hat{s}^2} \, |M|^2_{\Sigma,av} \quad , \tag{16}$$

with $|M|^2_{\Sigma,av}$ being the matrix element squared for $\gamma g \to J/\psi g$ averaged (summed) over initial (final) state spins.

The color singlet model makes absolute predictions on the total cross section as well as on differential distributions. By comparing low energy photoproduction data with the prediction of this model it has been found that an overall K - factor of $K \sim 2$ is needed to describe the total cross section and moreover that the differential distributions, i.e. the z distribution with $z = \frac{P_p \cdot p_{J/\psi}}{P_p \cdot p_\gamma}$ being the inelasticity of the J/ψ, can only be described in a very limited region of phase space [8]. Especially in the high z region ($z > 0.8$) the model underestimates the measured cross section even with the mentioned K - factor.

In an improved color singlet model, where relativistic corrections to the bound state are taken into account by relaxing the requirement $p_c = p_{\bar{c}} = 1/2 p_{J/\psi}$ it has been found that the differential distributions $d\sigma/dz$ and $d^2\sigma/dp_\perp/dz$ are described very well up to the highest values of z [9].

Here only the matrix element squared for $\gamma g \to J/\psi g$ including relativistic corrections is recalled:

$$
\begin{aligned}
|M|^2_{\Sigma,av} \;=\; N \Big\{ & \left(1 + \frac{5}{3}\frac{\epsilon}{m_c}\right) \frac{\hat{u}^2}{(m^2_{J/\psi} - \hat{s})^2 (m^2_{J/\psi} - \hat{t})^2} \\
& - \frac{\epsilon}{12\, m_c} \Big[8 \left((m^2_{J/\psi} - \hat{s})^4 + (m^2_{J/\psi} - \hat{t})^4 \right) m^2_{J/\psi} \\
& - 4 \left((m^2_{J/\psi} - \hat{s})^3 + (m^2_{J/\psi} - \hat{t})^3 \right) \left(10\, m^4_{J/\psi} + 6 (m^2_{J/\psi} - \hat{s})(m^2_{J/\psi} - \hat{t}) \right) \\
& + \left((m^2_{J/\psi} - \hat{s})^2 + (m^2_{J/\psi} - \hat{t})^2 \right) \left(88\, m^4_{J/\psi} + 82 (m^2_{J/\psi} - \hat{s})(m^2_{J/\psi} - \hat{t}) \right) m^2_{J/\psi} \\
& - \left((m^2_{J/\psi} - \hat{s}) + (m^2_{J/\psi} - \hat{t}) \right) \Big(88\, m^8_{J/\psi} + 198 (m^2_{J/\psi} - \hat{s})(m^2_{J/\psi} - \hat{t})\, m^4_{J/\psi} \\
& + 21 (m^2_{J/\psi} - \hat{s})^2 (m^2_{J/\psi} - \hat{t})^2 \Big) \\
& + 32\, m^{10}_{J/\psi} + 228 (m^2_{J/\psi} - \hat{s})(m^2_{J/\psi} - \hat{t})\, m^6_{J/\psi} + 126 (m^2_{J/\psi} - \hat{s})^2 (m^2_{J/\psi} - \hat{t})^2\, m^2_{J/\psi} \Big] \\
& / \left((m^2_{J/\psi} - \hat{s})^3 (m^2_{J/\psi} - \hat{t})^3 (m^2_{J/\psi} - \hat{u}) \right) \\
& + \text{two cyclic permutations of } \hat{s},\, \hat{t} \text{ and } \hat{u} \Big\}
\end{aligned}
\tag{17}
$$

with $\hat{t} = (p_{J/\psi} - q)^2$, $\hat{s}$ is the center of mass energy of the incoming gluon and the photon and $\hat{u}$ is fixed by the relation $\hat{s} + \hat{t} + \hat{u} = m^2_{J/\psi}$. N includes the coupling constants as well as the wavefunction $|\psi(0)|^2$:

$$
N = \frac{32}{3} (4\pi\alpha_s)^2 \, (4\pi\alpha_{em})\, e_q^2\, m_{J/\psi}\, |\psi(0)|^2 \quad . \tag{18}
$$

ϵ/m_c can be thought of as the binding energy divided by the charm quark mass and is found to be $\epsilon/m_c = 0.16$ coming from data on J/ψ decay (for a detailed discussion see [9]). Setting $\epsilon/m_c = 0$ the nonrelativistic model of [6] is recovered.

Since higher order corrections are not yet calculated a constant K - factor has to be included when absolute predictions of the cross sections are made. A K - factor of $K = 2$ coming from analysis of low energy J/ψ photoproduction data seems reasonable for photoproduction. One should note that actually no K - factor is included in the program since this factor could be very different for different processes.

3.2.2 Elastic J/ψ photoproduction $\gamma p \to J/\psi p'$

Elastic J/ψ - photoproduction can be described by pomeron exchange. In a world where the pomeron $\mathbb{P}$ is made exclusively from gluons, the subprocess $\gamma g_{\mathbb{P}_1} g_{\mathbb{P}_2} \to J/\psi$, where $g_{\mathbb{P}}$ indicate that the gluons come from the pomeron, guarantees color and spin constraints of the J/ψ. Moreover the pomeron as a whole is interacting with the intermediate $c\bar{c}$ state of the photon just producing a real J/ψ meson.

This process has been modelled within the color singlet model [9]. Here only the cross section is given:

$$\frac{d\sigma}{dt} = \frac{\pi}{m^2_{J/\psi}\, s}\, f_{p\,\mathbb{P}}(t, r = \frac{m^2_{J/\Psi}}{s})\, \overline{|M(\mathbb{P}\gamma \to \mathrm{J}/\Psi)|^2} \quad , \tag{19}$$

with

$$\overline{|M(\mathbb{P}\gamma \to \mathrm{J}/\Psi)|^2} = \frac{8|\Psi(0)|^2\, e_q^2\, (4\pi\alpha_s)^2\, (4\pi\alpha)}{9\, m^3_{J/\Psi}} \, \frac{9}{64\, r^2_{\mathbb{P}}} \left(1 - \frac{11}{3}\, \frac{\epsilon}{m_c}\right) \quad . \tag{20}$$

The pomeron radius $r_{\mathbb{P}}$ has been estimated in [10] and is given by $r_{\mathbb{P}} = 0.5\ \mathrm{GeV}^{-1}$. Including a K - factor of $K \simeq 2$ this model describes elastic J/ψ photoproduction in the energy range available up to now (data are available for $\sqrt{s_{\gamma p}} < 30\mathrm{GeV}$) [9].

3.2.3 Hard diffractive J/ψ photoproduction $\gamma p \to J/\psi X p'$

Hard diffractive J/ψ photoproduction is a special part of the usual inelastic photoproduction. Again the hard subprocess is $\gamma g_{\mathbb{P}} \to J/\psi g$, but here only one gluon comes from the pomeron. Since by definition the pomeron is color neutral, there is no color flow from the hard subprocess to the proton resulting in a so called rapidity gap between the proton and the rest of the particles produced. The cross section for $\gamma + p \to J/\psi + X + p'$ as a function of the center of mass energy s of incoming photon and proton reads

$$\sigma_{\gamma p \to J/\psi X p'}(s) = \int f_{p\,\mathbb{P}}(t, r) \cdot G(x) \cdot \hat{\sigma}_{\gamma g \to J/\psi g}(\hat{s} = x\,r\,s)\,dr\,dx\,dt \quad . \tag{21}$$

Here $\hat{\sigma}(\hat{s})$ is the cross section for the hard subprocess $\gamma + g_{\mathbb{P}} \to J/\psi + g_2$.

This cross section must not be added to the inelastic one, since this process is part of the inelastic cross section but with different event signature.

3.2.4 J/ψ from B decays

J/ψ mesons can originate from the decay of B mesons via [11]:

$$\gamma g \to B\bar{B}(\to J/\psi X)$$

The matrix element for $B\bar{B}$ production via gamma gluon fusion is given by:

$$\overline{|M|^2} = (4\pi\alpha_s)(4\pi\alpha)e_Q^2 \left(\frac{m_b^2 - \hat{t}}{m_b^2 - \hat{u}} + (\frac{m_b^2 - \hat{u}}{m_b^2 - \hat{t}} + \frac{4m_b^2\hat{s}}{(m_b^2 - \hat{u})(m_b^2 - \hat{t})} - \frac{4m_b^4\hat{s}^2}{(m_b^2 - \hat{u})^2(m_b^2 - \hat{t})^2} \right)$$

with m_b, e_Q the mass and the charge of the b-quark. In the program at least one B meson is forced to decay into $J/\psi X$ via the LUND package.

3.2.5 J/ψ with associated $c\bar{c}$

The subprocess is has been calculated in [12]:

$$\gamma g \to J/\psi c\bar{c}$$

The matrix element is too long to be presented here. The $c\bar{c}$ state is obviously a color octed state, since the initial state carries color.

3.2.6 Resolved J/ψ photoproduction

Since (almost) real photons have a non neglegible hadronic component it is possible to define a photon structure function giving parton densities (quark and gluon densities) inside the photon. The quark and gluon from the photon (instead of the photon directly) can now interact with the partons from the proton [13]. This proecesses are very similar to hadroproduction except the different parton densities.

J/ψ mesons can be produced directly by gluon gluon fusion via the following subprocesses [14]:

$$gg \to J/\psi g$$

$$gg \to J/\psi \gamma$$

Both subprocesses are described by the matrixelement squared described in section 3.2.1 by simply changing the corresponding color factors and coupling constants.

However J/ψ's are also produced from the decay of χ mesons:

$$\chi_i \to J/\psi\gamma \quad i = 0, 1, 2$$

The matrix elements for $gq \to \chi_i q$ are given in [16] and simply repeated here:

$$\begin{aligned}
|M(gq \to \chi_0 q|^2 &= \frac{128}{9} \cdot \frac{\pi^2 \alpha_s^3 R_1^2}{m^3} \cdot \frac{(\hat{t} - 3m^2)^2(\hat{s}^2 + \hat{u}^2)}{(-\hat{t})(\hat{t} - m^2)^4} \\
|M(gq \to \chi_1 q|^2 &= \frac{256}{3} \cdot \frac{\pi^2 \alpha_s^3 R_1^2}{m^3} \cdot \frac{(-\hat{t})(\hat{s}^2 + \hat{u}^2) - 4m^2\hat{s}\hat{u}}{(\hat{t} - m^2)^4} \\
|M(gq \to \chi_2 q|^2 &= \frac{256}{9} \cdot \frac{\pi^2 \alpha_s^3 R_1^2}{m^3} \cdot \frac{(\hat{t} - m^2)^2(\hat{t}^2 + 6m^4) - 2\hat{s}\hat{u}(\hat{t}^2 - 6m^2(\hat{t} - m^2))}{(-\hat{t})(\hat{t} - m^2)^4}
\end{aligned}$$

The matrix elements for $gg \to \chi_i g$ are given in [17] and simply repeated here:

$$\begin{aligned}
|M(gg \to \chi_0 g|^2 &= \frac{32\pi^2 \alpha_s^3 R_1^2}{m^3} \cdot \frac{1}{\left[(\hat{s} - m^2)(\hat{t} - m^2)(\hat{u} - m^2)\right]^2} \\
&\times \left[8m^2 \left(\frac{\hat{t}\hat{u}(\hat{t}^4 - \hat{t}^2\hat{u}^2 + \hat{u}^4)}{(\hat{s} - m^2)^2} + \frac{\hat{u}\hat{s}(\hat{u}^4 - \hat{u}^2\hat{s}^2 + \hat{s}^4)}{(\hat{t} - m^2)^2} + \frac{\hat{s}\hat{t}(\hat{s}^4 - \hat{s}^2\hat{t}^2 + \hat{t}^4)}{(\hat{u} - m^2)^2} \right) \right.
\end{aligned}$$

$$
\begin{aligned}
&+4m^4[m^2(\hat{s}\hat{t}+\hat{t}\hat{u}+\hat{u}\hat{s})-5\hat{s}\hat{t}\hat{u}]+(\hat{s}\hat{t}+\hat{t}\hat{u}+\hat{u}\hat{s})^2\\
&\times\left(\frac{9m^8}{\hat{s}\hat{t}\hat{u}}+\frac{1}{(\hat{s}-m^2)(\hat{t}-m^2)(\hat{u}-m^2)}\Big\{8m^4(\hat{s}^2+\hat{t}^2+\hat{u}^2)-16m^2\hat{s}\hat{t}\hat{u}\right.\\
&\left.+\left[1-9m^2(\frac{1}{\hat{s}}+\frac{1}{\hat{t}}+\frac{1}{\hat{u}})\right](\hat{s}^4+\hat{t}^4+\hat{u}^4)\Big\}\right)\Bigg]
\end{aligned}
$$

$$
\begin{aligned}
|M(gg\to\chi_1 g|^2 &= \frac{192\pi^2\alpha_s^3R_1^2}{m^3}\cdot\frac{1}{\left[(\hat{s}-m^2)(\hat{t}-m^2)(\hat{u}-m^2)\right]^2}\\
&\times\left[m^2\left(\frac{\hat{t}^2\hat{u}^2(\hat{t}^2+\hat{u}^2)}{(\hat{s}-m^2)^2}+\frac{\hat{u}^2\hat{s}^2(\hat{u}^2+\hat{s}^2)}{(\hat{t}-m^2)^2}+\frac{\hat{s}^2\hat{t}^2(\hat{s}^2+\hat{t}^2)}{(\hat{u}-m^2)^2}\right)\right.\\
&\left.+\frac{2(\hat{s}^2\hat{t}^2+\hat{t}^2\hat{u}^2+\hat{u}^2\hat{s}^2)(\hat{s}^2\hat{t}^2+\hat{t}^2\hat{u}^2+\hat{u}^2\hat{s}^2+m^2\hat{s}\hat{t}\hat{u})}{(\hat{s}-m^2)(\hat{t}-m^2)(\hat{u}-m^2)}\right]
\end{aligned}
$$

$$
\begin{aligned}
|M(gg\to\chi_2 g|^2 &= \frac{64\pi^2\alpha_s^3R_1^2}{m^3}\cdot\frac{1}{\left[(\hat{s}-m^2)(\hat{t}-m^2)(\hat{u}-m^2)\right]^2}\\
&\times\left[m^2\left(\frac{\hat{t}^2\hat{u}^2(\hat{t}^2+4\hat{t}\hat{u}+\hat{u}^2)}{(\hat{s}-m^2)^2}+\frac{\hat{u}^2\hat{s}^2(\hat{u}^2+4\hat{u}\hat{s}+\hat{s}^2)}{(\hat{t}-m^2)^2}+\frac{\hat{s}^2\hat{t}^2(\hat{s}^2+4\hat{s}\hat{t}+\hat{t}^2)}{(\hat{u}-m^2)^2}\right)\right.\\
&+12m^2[3(\hat{s}^3\hat{t}+\hat{t}^3\hat{u}+\hat{u}^3\hat{s}+\hat{s}\hat{t}^3+\hat{t}\hat{u}^3+\hat{u}\hat{s}^3)+4m^2\hat{s}\hat{t}\hat{u}]\\
&+\frac{2(\hat{s}\hat{t}+\hat{t}\hat{u}+\hat{u}\hat{s}-m^4)(\hat{s}\hat{t}+\hat{t}\hat{u}+\hat{u}\hat{s})^2}{(\hat{s}-m^2)(\hat{t}-m^2)(\hat{u}-m^2)}\Big[\hat{s}\hat{t}+\hat{t}\hat{u}+\hat{u}\hat{s}-24m^4\\
&\left.-6m^2(\hat{s}\hat{t}+\hat{t}\hat{u}+\hat{u}\hat{s}-m^4)(\frac{1}{\hat{s}}+\frac{1}{\hat{t}}+\frac{1}{\hat{u}})\Big]\right]
\end{aligned}
$$

In all above formulas $m^2 = m^2_{\chi_i}$ and $R_1^2 = 9.1\cdot 10^{-3}\cdot m^2$ is the P - wave function at the origin calculated from the decay width.

The branching ratios for $\chi_i \to J/\psi\gamma$ are :

$$BR(\chi_0 \to J/\psi\gamma) = 0.09$$

$$BR(\chi_1 \to J/\psi\gamma) = 0.27$$

$$BR(\chi_2 \to J/\psi\gamma) = 0.14$$

3.2.7 Double J/ψ production

In the picture of the color singlet model two J/ψ mesons can be produced simultaneously via ([18]):

$$q\bar{q} \rightarrow J/\psi J/\psi$$

$$gg \rightarrow J/\psi J/\psi$$

The matrixelements for this processes are too long to be presented here. The process $gg \rightarrow J/\psi J/\psi$ is sensitive to the polarisation of the two incoming gluons and different polarisation states are reflected in the angular distribution of the two J/ψ mesons in the gg center-of-mass system as pointed out in [18].

The summation over initial and final polarisation states is done explicitely in the program allowing for polarised beams.

3.3 J/ψ - hadroproduction

All subprocesses mentioned in section 3.2.6 for resolved J/ψ photoproduction apply also for J/ψ - hadroproduction.

4 QCD shower evolution

Higher order QCD effects are taken into account using the leading log parton shower approach. Starting from the hard scattering process with x_1 and x_2 being the fractional momenta of the two interacting partons at a suitable scale μ^2, a backward evolution according to the Altarelli Parisi (AP) equations will lead to larger x_i and smaller μ^2 values. Thus especially at high CM energies initial state QCD radiation will become important since at small x values at the hard scattering there is plenty of space for radiation when starting from a initiating parton at higher momentum.

In $p\bar{p}$ collisions the "$\hat{s}$ approach" is widely used (in PYTHIA) whereas a different approach in leptoproduction is adopted in LEPTO. Starting from the hard interaction process at some suitable scale μ^2 choosen ($\mu^2 = \hat{s}, m^2, m^2+$

$p_\perp^2$) the partons are evolved backward. This backward evolution is quite complicated and the reason is that in the Monte Carlo progam the kinematic variables are first chosen according to the hard scattering process.

The probabilities for a branching to happen are given by the AP evolution equations

$$\frac{d f_a(x,t)}{dt} = \frac{\alpha_s(t)}{2\pi} \sum_a \int_x^1 \frac{dx'}{x'} f_a(x',t) P_{a\to bc}\left(\frac{x}{x'}\right) \tag{22}$$

where $f_i(x,t)$ are the parton density functions, giving the probability of finding a parton i carrying the fraction x of the total hadron momentum probed at scale t. $P_{a\to bc}$ are the AP splitting functions:

$$P_{q\to qg}(z) = \frac{4}{3}\frac{1+z^2}{1-z} \tag{23}$$

$$P_{g\to gg}(z) = 6\frac{(1-z(1-z))^2}{z(1-z)} \tag{24}$$

$$P_{g\to q\bar{q}} = \frac{1}{2}(z^2 + (1-z)^2) \tag{25}$$

Soft gluon emission causes problems, since the AP functions for $P_{q\to qg}$, $P_{g\to gg}$ are divergent as $z \to 1$. In order to avoid divergencies, a upper cutoff z_{max} is introduced and the remaining soft gluon emisson is treated as an effective shift in z (for details see [19]).

The initiators of the parton shower cascade (partons inside the proton for example) are treated collinear with the original particle when effects from primordial k_t are neglected and have neglegible mass ($m^2 \leq 1$ GeV). When a branching occurs, $p_3 \to p_1 + p_2$, the daughter partons p_1 and p_2 will have transverse momenta and virtualities greater than that of the initiator p_3. Thus after the QCD cascade the partons going into the hard interaction also have transverse momenta compared to the non parton shower case.

In γp and $p\bar{p}$ collisions there is no problem associated with this treatment since the kinematics of the hard interaction usually cannot be determined by measuring the scattered beamparticles either because the beamparticle is totally absorbed (the photon in γp) or because the beamparticle is insufficiently measured by experiment. However in leptoproduction the kinematics are usually defined by the scattered lepton (y, Q^2 for example). In that case there will be mismatch between the generated y, Q^2 (before the parton cascade) and after QCD radiation has been added mainly because of the additional transverse momentum. For leptoproduction a special approach has been developed ("LEPTO approach") in order to keep the scattered lepton and the (virtual) photon unchanged even with initial state parton shower.

In order to study both approaches ("$\hat{s}$-approach" for $p\bar{p}$ and ep collisions and "LEPTO approach" for ep and γp collisions) a few changes had to be done to the formulas given in [20] for the LEPTO approach in order to account for $Q^2 = 0$ for (quasi) real photoproduction. In the following the relevant formulas are given for γp CM system with the photon momentum $q = (W^2 - Q^2, 0, 0, W^2 + Q^2)/2W = (q_0, 0, 0, q_z)$ with $W^2 = ys - Q^2 + m_p^2$. The energy fraction z_1 for branching $p_3 \to p_1 + p_2$ is defined as:

$$z_1 = \frac{p_1.q - Q_1^2}{p_3.q - Q_3^2} \tag{26}$$

where p_1 is the four momentum of the parton going into the hard interaction with virtuality $p_1^2 = -Q_1^2$ and $p_3 \to p_1 + p_2$ being the initiator of the first branching in the backward evolution with $p_3^2 = -Q_3^2$. The kinematics of the branching are constructed in analogy with the formuals given in [19, 20]. In terms of the combinations

$$s_1 = (p+q)^2 + Q^2 + Q_1^2 \tag{27}$$

$$s_3 = \frac{s_1 - 2Q_1^2}{z_1} + 2Q_3^2 \tag{28}$$

$$r_1 = \sqrt{s_1^2 - 4Q^2 Q_1^2} \tag{29}$$

$$r_3 = \sqrt{s_3^2 - 4Q^2 Q_3^2} \tag{30}$$

the maximum virtuality of the timelike parton 2 in the branching $3 \to 1 + 2$ is given by:

$$(m_2^2)_{max} = \frac{s_1 s_3 - r_1 r_3}{2Q^2} - Q_1^2 - Q_3^2 \text{ for } Q^2 \neq 0 \tag{31}$$

$$(m_2^2)_{max} = \frac{s_1^2 Q_3^2 + s_3^2 Q_1^2}{s_1 s_3} - Q_1^2 - Q_3^2 \text{ for } Q^2 = 0 \tag{32}$$

Now using the relation $m_2^2 = p_2^2 = (p_3 - p_1)^2$ energy and momentum of parton 3 is found for $Q^2 \neq 0$ as:

$$E_3 = \frac{1}{2} \frac{p_{1z} s_3 + q_z (Q_1^2 + Q_3^2 + m_2^2)}{p_{1z} q_0 - E_1 q_z} \tag{33}$$

$$p_{3z} = \frac{1}{2} \frac{E_1 s_3 + q_0 (Q_1^2 + Q_3^2 + m_2^2)}{p_{1z} q_0 - E_1 q_z} \tag{34}$$

and for $Q^2 = 0$:

$$E_3 = \frac{s_1^2 - 4 q_z^2 Q_3^2}{4 q_0 s_3} \tag{35}$$

$$p_{3z} = \frac{s_1^2 + 4 q_0^2 Q_3^2}{4 q_z s_3} \tag{36}$$

The transverse momentum in both cases is given by:

$$p_{t3}^2 = E_3^2 - p_{3z}^2 + Q_3^2 = [(m_2^2)_{max} - m_2^2] \frac{s_1 s_3 + r_1 r_3 - 2Q^2(Q_1^2 + Q_3^2 + m_2^2)}{2 r_1^2} \tag{37}$$

Thus the construction of the $3 \to 1 + 2$ vertex is completed. With these necessary changes for $Q^2 \simeq 0$, the machinery of LEPTO [25] can be used.

4.1 Beam Remnant and Fragmentation

The hadronisation part is done via the LUND string fragmentation model [21]. This model has also implications on the picture of the beam remnants.

Whenever a parton carrying color is removed from one of the beam particles a colored beam rmnant is left. This beam remnant together with the colored partons of the hard interaction have to form a color singlet state.

If a gluon is removed from the proton, a quark and a diquark is left. We assume here that the gluon was radiated from the quark, and that the color of the gluon together with the color of the remnant quark must give the color of the initial quark.

In case of inelastic J/ψ photoproduction ($\gamma g_1 \to J P g_2$) g_1 carries the same color as g_2. Therefore the only way to produce a color singlet final state is that g_2 connects the remnant quark and diquark together.

In case of heavy quark photoproduction ($\gamma g \to b\bar{b}$) the color - anticolor of the gluon goes to the quark and antiquark, respectively. Here $\bar{b}$ is connected via a color string to the remnant quark and the b to the remnant diquark. The same color flow situation occurs for $\gamma g \to J/\psi c\bar{c}$.

A somewhat special case is diffractive inelastic J/ψ photoproduction via $\gamma g_{\mathbb{P}} \to J/\psi g_2$. Here the proton stays intact, or at least has no color connection to the other particles. When a gluon is removed from the color neutral pomeron $\mathbb{P}$ a color octed pomeron remnant is left, here treated as a single gluon. Now this pomeron remnant together with g_2 forms the color singlet state.

In case of resolved photoproduction the stuation becomes more complicated. If a gluon is emitted from a photon, then the photon remnant is a color octet gluonic state, described for simplicity by a single gluon. If a quark is picked out of the photon the photon remnant is simply a anti-quark with the corresponding anti-color.

Scattering on a sea quark of the proton can be modelled as radiating a gluon from the proton with this gluon splitting into the quarks q_2 and $\bar{q}_2$. The proton remnant in such a case is a meson (from q_p and $\bar{q}_2$) and a diquark. If a anti-quark of the proton sea is removed the proton remnant is a baryon (from the diquark and q_2) and a quark q_p.

In case of pp or $p\bar{p}$ collisions the situation is similar to that for the resolved photon in terms of color flow. However the remnant is different.

When parton showers are included the color flow goes via subsequent gluons (radiated in the parton shower) and they belong to the same color singlet string. However when a gluon splits into $q\bar{q}$ the color flow is broken.

5 Description of the program components

The main routines are:

EPJPSIG	main program
GJPINI	initializes the program

EPJPSI performs integration of the cross section. This routine has to be called before event generation can start.

JPEND prints cross section and the number of events.

EVENT performs the event generation and call to LMEPS

PYSTFU proton structure function from PYTHIA.

PYSTPO polarised proton structure function.

LMEPS rearrangemnet of event record. Calls to EPCOL, PYSSPA, PYREMN.

EPCOL defines color flow for various processes

PYSSPA administer routine for initial state parton shower. Copy of LEPTO 6.1 routine with changes for $Q^2 = 0$. For PYTHIA approach this is a copy of the corresponding part in PYTHIA.

PYREMN remnant treatment a la LEPTO and PYTHIA. Copied from LEPTO 6.1 with changes according to $Q^2 = 0$ for photoproduction as well as changes according to PYTHIA 5.6

ALPHAS(RQ give $\alpha_s(\mu)$ with μ =RQ.

PARTI treatment of initial parton momenta well as the corresponding density distributions like EPA or structure functions. Also treat resolved photon kinematics. Calls to PYSTFU and PYSTPO.

DFUN interface to FXN1

FXN1 calls routines for selected processes: DIRECT, RESOLV, RESOL1, DIFFRA, DIFFR1, DIFFEL, JPSICC, JPSIJPSI, BBAR

CUTG(IPSI) cuts for process IPSI in integration and event generation. At present only for IPSI=2 $p_{t\,min} = 1$ GeV.

FRAG color flow for diffractive processes and setting parameters for the decay $B \to J/\psi X$.

DIRECT IPSI=1 $\gamma g \to J/\psi g$ calls kinematics and phase space routine PARTO and matrix element ELEMDI.

RESOLV IPSI=2 $qg \to \chi q$ and $gg \to \chi g$. calls kinematics and phase space routine PARTO and matrix element ELEMRE.

RESOL1 IPSI=3 $gg \to J/\psi g$ and $gg \to J/\psi\gamma$ calls kinematics and phase space routine PARTO and matrix element ELEMDI.

DIFFRA IPSI=10 $\gamma g_{\mathrm{I\!P}} \rightarrow J/\psi g$. calls kinematics and phase space routine PARTDF and matrix element ELEMDI. Here $g_{\mathrm{I\!P}}$ a gluon coming from a pomeron.

DIFFR1 IPSI=11 $\gamma g_{PO} \rightarrow c\bar{c}$. calls kinematics and phase space routine PARTDF and matrix element ELEQQB. The $c\bar{c}$ together with the pomeron remnant (gluon) forms a J/ψ.

DIFFEL IPSI=12 $\gamma \mathrm{I\!P} \rightarrow$ J/ψ calls kinematics and phase space routine PARTDF

JPSICC IPSI=20 $\gamma g \rightarrow J/\psi c\bar{c}$ calls kinematics and phase space routine PARTO and matrix element ELEMCC.

JPSIJPSI IPSI=21,22 $gg \rightarrow J/\psi J/\psi$ and $q\bar{q} \rightarrow J/\psi J/\psi$ calls kinematics and phase space routine PARTO and matrix element ELJJGG and ELJJQQ.

BBAR IPSI=30 $\gamma g \rightarrow B\bar{B}$. calls kinematics and phase space routine PARTO and matrix elemant ELEQQB for

ELEMDI matrix element for $\gamma g \rightarrow J/\psi g$ and $gg \rightarrow J/\psi g$ including relativistic corrections.

ELEMRE matrix element for $gq \rightarrow \chi q$ and $gg \rightarrow \chi g$.

ELEQQB matrix element for $\gamma g \rightarrow Q\bar{Q}$ including masses. Q stands for heavy quark.

ELJJGG matrix element for $gg \rightarrow J/\psi J/\psi$.

ELJJQQ matrix element for $q\bar{q} \rightarrow J/\psi J/\psi$.

ELEMCC matrix element for $\gamma g \rightarrow J/\psi c\bar{c}$

CLUSTE simplified version of LUPREP (JETSET). The $c\bar{c}g$ forms a J/ψ state if its mass is below the threshold for D production.

DOT(A,B) A.B four vector dot product

CDOT(A,B) A.B four vector dot product with A complex vector

CCDOT(A,B) A.B four vector dot product with A,B complex vectors

DOT1(I,J) four vector dot product of vectors I and J in LUJETS common.

BOOK histogram booking

DVNOPT changing options for DIVON

RANUMS vector of random numbers used in event generation.

PHASE phase space and generation for momenta of final partons in hard subprocess. $2 \rightarrow 2$ and $2 \rightarrow 3$ processes.

LREMH	energy momentum fraction for target splitting. Copy from LEPTO 6.1
LPRIKT	generates magnitude and azimuthal angle for Gaussian primorial k_t of parton in nucleon. Copy from LEPTO 6.1
PYREMN, PYSPLI	treatment of target remnant and primordial k_t. copy from LEPTO 6.1 with modifications for $Q^2 = 0$ in photoproduction and modifications according to PYTHIA 5.6
PYSSPA	simulate initial state parton shower. copied from LEPTO 6.1 with changes for $Q^2 = 0$ in photoproduction.
PARTO	phase space and event record for all processes exept diffractive ones.
PARTDF	phase space and event record for diffractive processes.

COMMON/JPSI /EPSM,IPSI,IRUNA,IWPSI,IQ2,NPSTR,NPSTP,NGSTR

Parameters:

EPSM:	$\epsilon/m_c = 0.16$ (D)
IPSI:	select process to be generated
	=1: $\gamma g \to J/\psi g$ (default (D))
	=2: $q(g)q(g) \to \chi(\to J/\psi\gamma)q(g)$
	=3: $gg \to J/\psi g(\gamma)$
	=10: $\gamma g_{\mathbb{P}} \to J/\psi g$
	=11: $\gamma g_{\mathbb{P}} \to J/\psi$ according to clustering model
	=12: $\gamma\mathbb{P} \to$ J/ψ
	=20: $\gamma g \to c\bar{c}J/\psi$
	=21: $gg \to J/\psi J/\psi$
	=22: $q\bar{q} \to J/\psi J/\psi$
	=30: $\gamma g \to b\bar{b}(\to J/\psi X)$
	The program EPJPSI3.0 is not able to produce mixed event samples of different J/ψ production mechanisms.
IRUNA:	switch for running α_s
	=0: fixed $\alpha_s = 0.3$ (D)
	=1: running $\alpha_s(Q^2)$ (first order)
IWPSI:	switch for leptonic decay width Γ_{ll} of J/ψ
	=0: (D) width Γ_{ll}^0 without radiative corrections.

=1: width Γ_{ll} corrected according to eq.(14)

IQ2: select scale Q^2 for $\alpha_s(Q^2)$ and $xG(x,Q^2)$

=1: $Q^2 = m^2_{J/\psi}$(D)

=2: $Q^2 = \hat{s}$

=3: $Q^2 = m^2 + p_\perp^2$

NPSTR: select p structure function (as in PYTHIA) (D=1005006)

=0: simple scaling function

=1: EHLQ set 1

=2: EHLQ set 2

=3: Duke-Owens set 1

=4: Duke-Owens set 2

=5: Morfin-Tung set 1

=6: Morfin-Tung set 2

=7: Morfin-Tung set 3

=8: Morfin-Tung set 4

=9: Gluck-Reya-Vogt LO set

=10: Gluck-Reya-Vogt HO set

=11: Diemoz-Ferroni-Longo-Martinelli set 1

=12: Diemoz-Ferroni-Longo-Martinelli set 1

=13: Diemoz-Ferroni-Longo-Martinelli set 1

=13: Diemoz-Ferroni-Longo-Martinelli set 1

$>$ 20 parameterization from PDFLIB [22, 23] is used according to the following coding scheme:

1000000 $\times$ NPTYPE+1000 $\times$ NGROUP+NSET

example: 1005006 for NPTYPE 1 Ngroup 5 Nset 6 for GRV HO proton parton density.

NPSTP: select polarised p structure function

=1: Ross Roberts set 1 $\Delta G = 0$

=2: Ross Roberts set 2 (D)

=3: Schäfer; no sea no gluons

$>$ 20 (D=1005010) parameterization from PDFLIB [22, 23] is used according to the following coding scheme:

1000000 $\times$ NPTYPE+1000 $\times$ NGROUP+NSET

example: 1005010 for NPTYPE 1 Ngroup 5 Nset 10 polarised proton structure function GRSV.

NGSTR: select γ structure function

> 20 (D=3005001) parameterization from PDFLIB [22, 23] is used according to the following coding scheme: $3000000 \times$ NPTYPE+$1000 \times$ NGROUP+NSET example: 3005001 for NPTYPE 3 Ngroup 5 Nset 1 photon structure function GRV.

COMMON/JPSPO/ N1POL,N2POL,NE1PO1,NE1PO2,NE2PO1,NE2PO2

Parameters:

N1POL:	give polarisation of incoming particle 1 =0: no polarisation =1: polarisation + 1 =-1: polarisation -1
N2POL:	give polarisation of incoming particle 2 =0: no polarisation =1: polarisation + 1 =-1: polarisation -1
NE1PO1 :	give polarisation of outgoing J/ψ_1.
NE1PO2 :	give polarisation of outgoing J/ψ_1. If NE1PO1=NE1PO2 only one polarisation state is generated, otherwise from NE1PO1 to NE1PO2. If NE1PO1=-1 and NE1PO2 = 1 all polarisation states are included.
NE2PO1 :	give polarisation of outgoing J/ψ_2.
NE2PO2 :	give polarisation of outgoing J/ψ_2. If NE2PO1=NE2PO2 only one polarisation state is generated, otherwise from NE2PO1 to NE2PO2. If NE2PO1=-1 and NE2PO2 = 1 all polarisation states are included.

COMMON/JPSGKI/ YY,XEL,XPR,PT2H,SHH

Parameters:

YY :	energy fraction lost by incident beam particle A
XEL :	energy fraction of parton on the side of beam particle A
XPR :	energy fraction of parton on the side of beam particle B
PT2H :	$p_\perp^2$ [GeV$^2/c^2$] of parton in hard subprocess cm system
SHH :	invariant mass $\hat{s}$ [GeV^2] of hard subprocess

COMMON/INPU /PLEPIN,PPIN,NFRAG,ILEPTO,IFPS

Parameters:

PLEPIN :	momentum p [GeV/c] of incoming beam particle A (D=-30.)
PIN :	momentum p [GeV/c] of incoming beam particle B (D=820.)
NFRAG :	switch for fragmentation = 0 off = 1 on (D)
ILEPTO :	switch for initial state parton shower = 1 initial state parton shower according to LEPTO treatment for photoproduction = 0 according to PYTHIA treatment $\hat{s}$ approach for photo and hadroproduction
IFPS :	switch parton shower = 0 no parton shower = 1 inital state parton shower = 2 final state parton shower = 3 initial and final state parton shower (D)

COMMON/COLOR/ XPQ(-25:25),XPDQ(-25:25),XGQ(-25:25),XGDQ(-25:25)

Parameters:

XPQ :	parton density of beam particle B
XPDQ :	polarised parton density of beam particle B
XGQ :	parton density at photon side (resolved photon case) or proton side ($p\bar{p}$ case)
XGDQ :	polarised parton density at photon side (resolved photon case) or proton side ($p\bar{p}$ case)

COMMON/DIFFR/T2MAX,XF,ALPHP,RN2,EPSP,RPO,NG

Parameters:

T2MAX :	maximum t [GeV^2/c^2] for diffractive process (D: 20)
XF :	minimum $x_f = \frac{E_p}{E_{p'}}$ (D: XF = 0.9)
ALPHP :	$\alpha_{\mathbb{P}}$ (D: $\alpha_{\mathbb{P}} = 0.25$ GeV^{-2})
RN2 :	R_N^2 as defined above (D: 3.3)
EPSP :	$\hat{\epsilon}$ (D: $\hat{\epsilon} = 0.085$)
RPO :	$r_{\mathbb{P}}$ pomeron radius (D: $r_{\mathbb{P}} = 0.5$)
NG :	select pomeron structure function

=0: $G_0(x) = 6(1-x)$ (D)
=n: $G_n(x) = (n+1)\,\frac{(1-x)^n}{x}$ for $1 \leq n \leq 5$

COMMON /PARTON/ SSS,CM(4),DBCMS(4)

Parameters:	
SSS	overall s
CM	boost vector to overall center of mass system
DBCMS	boost vector to hard scattering center of mass system

COMMON /BEAM/PBEAM(2,5),KBEAM(2,5)

Parameters:	
PBEAM	energy momentum vector of beam particles
KBEAM	flavour code of beam partciles

COMMON/LUCO /KE,KP,KPH,KGL,KPSI,KCHI,KPA

Parameters:	for internal use only

COMMON/HARD/ NIA1,NIR1,NIA2,NIR2,NF1,NF2,NFT

Parameters:	for internal use only
NIA1,NIA2	position of partons in hard interaction in LUJETS event record
NF1,NF2	first and last position final partons/particles of hard interaction in LUJETS
NIR1,NIR2	first and last position of remnant
NFT	total number of final particles; for $2 \to 2$ process NFT=2

COMMON /PARAT/AM(18),SHAT,YMAX,YMIN,Q2MAX,Q2MIN,XMAX,XMI

Parameters:	
AM	masses of final state particles of hard interaction
SHAT	$\hat{s}$ of hard subprocess
YMAX,YMIN	upper and lower limits for x_1; in case of photoproduction upper and lower limits for energy fraction of quasi real γ.
Q2MAX,Q2MIN	only relvant for photoproduction; upper and lower limits for Q^2 of γ.
XMAX,XMIN	upper and lower limits for x_2.

COMMON /PARAE/Q2,Q2Q,PCM(4,18)

Parameters:

Q2	in case of photoproduction: actual Q^2 of γ.
Q2Q	hard scattering scale μ^2 used in α_s and structure functions
PCM	particle momenta in double precision in hard interaction in CM- frame.

COMMON /PARA/ WPSI,ALPHS,PI,ALPH,IWEI

Parameters:

WPSI	actual Γ_{ll} decay width of J/ψ
ALPHS	actual α_s
PI	π
ALPH	α_{em}
IWEI	=1 flag indicating unweighted event generation. = 0 weighted events (during integration).

COMMON/EFFIC/AVGI,SD,NIN,NOUT

Parameters:

AVGI	integrated cross section
SD	standard deviation of integrated cross section
NIN	number of trials for event generation
NOUT	number of successful generated events

COMMON/DENSITY/ D(20),VI(20),DS(20)

Parameters:

D,VI,DS	for internal use

COMMON/DENSPOL/ XUP1(-5:5),XDP1(-5:5),XUP2(-5:5),XDP2(-5:5)

Parameters:

XUP1,XDP1,XUP2,XDP2	for internal use

COMMON/STRU/ SCAL1,XPD1,SCAL2,XPD2

Parameters:

SCAL1,SCAL2	scale for structure function on beam particle A and B
XDP1,XPD2	value of parton density on beam particle A and B

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