HIPPOPO
a Monte Carlo generator for particle production in the Quark Gluon String Model

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1 Introduction

HIPPOPO (Hadron Induced Particle Production Off Pomeron Outpour) is a program to simulate the production of hadrons via the multipomeron exchange mechanism in a high energy hadron collision. The underlying algorithm is based upon the Quark Gluon String Model developed over the years by many authors [1]-[20].

For the initial colliding beams the User can choose among the following species: nucleons, atomic nuclei, \( \pi \), \( K \), \( \phi \) and \( J/\psi \) mesons, \( \Lambda \), \( \Sigma \) and \( \Xi \) hyperons (of any explicitly stated charge), and their antiparticles. Also, the program allows photon beams. In the latter case, the photon is treated as a superposition of \( \rho \), \( \phi \) and \( J/\psi \) mesons according to the Vector Dominance Model.

The produced hadron may be a \( \pi \), \( \eta \), \( \rho \), \( \omega \), \( K \), \( \phi \), \( D \), \( D_s \) or \( J/\psi \) meson, nucleon \( N \), \( \Lambda \), \( \Sigma \), \( \Xi \) or \( \Omega \) hyperon, \( \Lambda_c \) or \( \Xi_c \) baryon, an antiparticle or an excited state of any mentioned hadron.

The program yields the fully differential inclusive cross section. However, it is not a full event generator, because it only focuses on the inclusive production properties of the user-defined hadron, while the accompanying particles are not taken into account.

2 Physics input

An interaction between the colliding hadrons is assumed to proceed by means of the multipomeron exchange mechanism. The particular contribution to the cross section due to the exchange of \( n \) Pomerons reads [4]:

\[
\sigma_n(\xi) = \frac{\sigma_P}{nz} \left( 1 - e^{-z} \sum_{k=0}^{n-1} \frac{z^k}{k!} \right), \quad n \geq 1
\]  

(1)

with

\[
\xi = \ln s, \quad \sigma_P = 8\pi\gamma_P e^{\xi\Delta}, \quad z = 2C\gamma_P [R^2 + \alpha' P \xi]^{-1} s^\Delta,
\]

and \( C \), \( \gamma_P \), \( R^2 \), \( \alpha' P \) and \( \Delta \) being the model parameters (see section 3.3 for their numerical values). Also, there exist contributions from the elastic and diffraction dissociation processes, \( \sigma_{el} \) and \( \sigma_{DD} \), which correspond to the absence of Pomerons \( (n = 0) \):

\[
\sigma_0(\xi) = \sigma_P \left[ f(\frac{\xi}{2}) - f(z) \right] \quad \text{with} \quad f(z) = \sum_{\nu=1}^{\infty} \frac{(-z)^{\nu-1}}{\nu \nu!},
\]  

(2)

\[
\sigma_{el} = (1/C) \sigma_0(\xi), \quad \sigma_{DD} = (1 - 1/C) \sigma_0(\xi).
\]  

(3)
Summing up, the total inelastic cross section is:

\[ \sigma_{\text{tot}} = \sigma_{\text{DD}} + \sum_{n=1}^{\infty} \sigma_{n}. \]  

(4)

According to the Quark Gluon String Model, each Pomeron is treated as a pair of colour strings attached to the partons in the colliding hadrons. The fragmentation of colour strings results in the production of particles. The inclusive differential cross section for a hadron of type \( h \) reads:

\[ \frac{d\sigma^h}{d^2p_T dy} = \sigma_{\text{DD}} \varphi^h_{\text{DD}} + \sum_{n=1}^{\infty} \sigma_n \varphi^h_{n}, \]  

(5)

where the particle production from Pomeron strings is described by the string fragmentation functions \( \varphi_n \):

\[ \varphi^h_n = a^h [ F_{\text{val}}^h(x_+, n) F_{\text{val}}^h(x_-, n) + F_{\text{val}}^h(x_+, n) F_{\text{val}}^h(x_-, n) + (n-1)[ F_{\text{sea}}^h(x_+, n) F_{\text{sea}}^h(x_-, n) + F_{\text{sea}}^h(x_+, n) F_{\text{sea}}^h(x_-, n) ], \]

(6)

with \( x_{\pm} = \frac{1}{2}[x_{\perp}^2 + x_T^2]^{1/2} \pm x_F \), \( x_{\perp} = 2m_{\perp}^2/\sqrt{s} \), so that \( x_+x_- = (m_{\perp}^2)^2/s \) and \( x_+-x_- = x_F \).

Each term in (6) corresponds to an independent string stretched between oppositely coloured partons from different beams. The contribution from each string is given by a product of two independent factors, \( F_i(x_{\mp}) \) and \( F_i(x_{\pm}) \), related to the endpoint partons (moving in the positive and negative directions, respectively). In turn, the factors \( F(x_{\pm}) \) are given by the convolution of universal functions:

\[ F^h(x_{\mp}, n) = \sum_i \int_{x_{\mp}}^1 f_i(x', n) G^h_i(x_{\mp}/x', p_T) T(x_F/x', p_T, n) dx', \]

(7)

where \( f_i(x, n) \) stands for the probability to find a parton of type \( i \) carrying the momentum fraction \( x \) in the beam hadron, and \( G^h_i(x, p_{\perp}) \) stands for the probability that the fragmentation of a type \( i \) parton yields a hadron \( h \) with the longitudinal momentum fraction \( x \) and transverse momentum \( p_{\perp} \). The parton distribution functions \( f_i(x, n) \) are specific for a given beam particle, and the fragmentation functions \( G^h_i(x, p_{\perp}) \) are specific for a given outstate hadron.

The diffraction dissociation term was taken in the form [16]

\[ \varphi^h_{\text{DD}} = \sqrt{x_+} F^h(x_+, 1) + \sqrt{x_-} F^h(x_-, 1) \]  

(8)

if the fragmenting and the produced particles are both baryons or both antibaryons, and

\[ \varphi^h_{\text{DD}} = (3/2)[\sqrt{x_+} + \sqrt{x_-}] F^h(x_+, 1) F^h(x_-, 1) \]  

(9)

in all other cases.

The parton distribution functions have the (Reggeon theory inspired) generic form:

\[ f(x, n) = x^{\alpha_f} (1-x)^{\beta_f+n-1} \]  

(10)

with the exponents \( \alpha_f \) and \( \beta_f \) determined by the flavour content of the beam particle. Similarly, the generic form of the parton fragmentation functions is:

\[ G(x, p_T) = x^{\alpha_g} (1-x)^{\beta_g+2\alpha_n p_T^2} \]  

(11)
with the exponents $\alpha_G$ and $\beta_G$ determined by the flavour content of the produced hadron. The parameters $\alpha_f$, $\beta_f$, $\alpha_G$ and $\beta_G$ are expressed in terms of the relevant Regge intercepts and represent the basic model assumptions. At the same time, to provide an interpolation between the limiting points $x \to 0$ and $x \to 1$, some extra factors may be introduced in the functions $G_h(x,p_T)$. The latter ones are only of phenomenological meaning and cannot be derived from ‘first principles’. The full list of parton distribution and fragmentation functions is too long to be presented in this paper, but these functions are easily readable from the FORTRAN code.

Finally, the weight function $T(z,p_T,n)$ in (7) is present for the hadron transverse momentum distribution. According to [13], it is parametrized in the form:

$$T(z,p_T,n) = [b_z^2/2\pi(1 + b_z m^h)] \exp[-b_z(m_{h \perp} - m^h)]$$

with $b_z = \gamma^h/[1 + (2 - 1/n)\rho z^2]$, and $\gamma^h$ and $\rho$ being still new phenomenological parameters.

### 3 Program components

#### 3.1 General structure and external references

The program structure is divided into several pieces. These are the user job cards and the initiating routines (collected in the file run.f); the table of parton distribution functions (file parton.f); the table of fragmentation functions (files fragm1.f, fragm2.f, fragm3.f); the particle production algorithm as described in Sect. 2 (file model.f); the Monte Carlo integration routine VEGAS [21] with its intrinsic random number generator (file vegas.f).

When evaluating the convolution in (7) the program refers to the standard function DGAUSS from CERN library. The normalizing factors for parton distribution functions are calculated with the use of the DGAMMA function, also from CERN library.

For histogramming purposes, the program uses the standard PAW package.

#### 3.2 Subroutines and Functions

SUBROUTINE CKNAME(i1,i2,ih)
Checks the consistency of the user given names for the beam and the produced particles.

SUBROUTINE PARAM
Introduces the model parameters.

SUBROUTINE HYBRID
Assignes model dependent intercepts to hybrid and excited states.

SUBROUTINE MIX
An algorithm to include composite beams (Atomic nuclei, for example) and hadrons of indefinite quark content (short and long living Kaons, $\eta'$ mesons, etc.).

SUBROUTINE CXNPOM(sqs,nmax)
Calculates the multipomeron cross sections, equ. (1).

FUNCTION F0(z)
Returns the $f(z)$ value, equ. (2).
FUNCTION FXN(xveg,wgt)
   The integrand expression for VEGAS [21], with xveg being the array of phase space
   variables and wgt the weight factor due to the particular phase space binning (supplied
   by VEGAS).

FUNCTION F1dif(x), F2dif(x)
   1st and 2nd beam diffractive dissociation functions.

FUNCTION F1val(x), F2val(x)
   1st and 2nd beam valent colour endpoint functions.

FUNCTION F1bar(x), F2bar(x)
   1st and 2nd beam valent anticolour endpoint functions.

FUNCTION F1v(x), F2v(x)
   1st and 2nd beam sea colour endpoint functions.

FUNCTION F1b(x), F2b(x)
   1st and 2nd beam sea anticolour endpoint functions.

FUNCTION T(zF,n,hmass,pt2)
   Transverse momentum distribution function.

SUBROUTINE NORM(nmax)
   Normalizes all parton distribution functions.

FUNCTION Bfun(ex,e1)
   Euler's Beta function.

FUNCTION FvalU(x,n,beam), FvalD(x,n,beam), FvalS(x,n,beam), FvalC(x,n,beam)
   Valen u, d, s, c quark distribution functions.

FUNCTION FbarU(x,n,beam), FbarD(x,n,beam), FbarS(x,n,beam), FbarC(x,n,beam)
   Valen u, d, s, c antiquark distribution functions.

FUNCTION FseaU(x,n,beam), FseaD(x,n,beam), FseaS(x,n,beam), FseaC(x,n,beam)
   Sea u, d, s, c quark distribution functions, apply to antiquarks also.

FUNCTION FvalUU(x,n,beam), FvalUD(x,n,beam), FvalDD(x,n,beam)
   Valen uu, ud, dd diquark distribution functions.

FUNCTION FvalUS(x,n,beam), FvalDS(x,n,beam), FvalSS(x,n,beam)
   Valen us, ds, ss diquark distribution functions.

FUNCTION FbarUU(x,n,beam), FbarUD(x,n,beam), FbarDD(x,n,beam)
   Valen uu, ud, dd antidiquark distribution functions.

FUNCTION FbarUS(x,n,beam), FbarDS(x,n,beam), FbarSS(x,n,beam)
   Valen us, ds, ss antidiquark distribution functions. In the above functions:
   x is the momentum fraction,
   n is the number of exchanged Pomerons,
   beam is the beam hadron the distribution functions refer to.
FUNCTION
DvalU(x,hadr,pt2), DvalD(x,hadr,pt2), DvalS(x,hadr,pt2), DvalC(x,hadr,pt2)
The $u$, $d$, $s$, $c$ quark diffraction dissociation functions.

FUNCTION
DbarU(x,hadr,pt2), DbarD(x,hadr,pt2), DbarS(x,hadr,pt2), DbarC(x,hadr,pt2)
The $u$, $d$, $s$, $c$ antiquark diffraction dissociation functions.

FUNCTION
DvalUU(x,hadr,pt2), DvalUD(x,hadr,pt2), DvalDD(x,hadr,pt2)
The $uu$, $ud$, $dd$ diquark diffraction dissociation functions.

FUNCTION
DvalUS(x,hadr,pt2), DvalDS(x,hadr,pt2), DvalSS(x,hadr,pt2)
The $us$, $ds$, $ss$ diquark diffraction dissociation functions.

FUNCTION
DbarUU(x,hadr,pt2), DbarUD(x,hadr,pt2), DbarDD(x,hadr,pt2)
The $uu$, $ud$, $dd$ antidiquark diffraction dissociation functions.

FUNCTION
DbarUS(x,hadr,pt2), DbarDS(x,hadr,pt2), DbarSS(x,hadr,pt2)
The $us$, $ds$, $ss$ antidiquark diffraction dissociation functions.

FUNCTION
GvalU(x,hadr,pt2), GvalD(x,hadr,pt2), GvalS(x,hadr,pt2), GvalC(x,hadr,pt2)
The $u$, $d$, $s$, $c$ quark fragmentation functions.

FUNCTION
GbarU(x,hadr,pt2), GbarD(x,hadr,pt2), GbarS(x,hadr,pt2), GbarC(x,hadr,pt2)
The $u$, $d$, $s$, $c$ antiquark fragmentation functions.

FUNCTION
GvalUU(x,hadr,pt2), GvalUD(x,hadr,pt2), GvalDD(x,hadr,pt2)
The $uu$, $ud$, $dd$ diquark fragmentation functions.

FUNCTION
GvalUS(x,hadr,pt2), GvalDS(x,hadr,pt2), GvalSS(x,hadr,pt2)
The $us$, $ds$, $ss$ diquark fragmentation functions.

FUNCTION
GbarUU(x,hadr,pt2), GbarUD(x,hadr,pt2), GbarDD(x,hadr,pt2)
The $uu$, $ud$, $dd$ antidiquark fragmentation functions.

FUNCTION
GbarUS(x,hadr,pt2), GbarDS(x,hadr,pt2), GbarSS(x,hadr,pt2)
The $us$, $ds$, $ss$ antidiquark fragmentation functions. In the above functions:
- $x$ is the momentum fraction,
- $hadr$ is the hadron to appear from fragmentation,
- $pt2$ is its transverse momentum squared.

SUBROUTINE DDMODE
Establishes the incoming and outcoming particle types as 'meson’, 'baryon’ or 'antibaryon’, that is important for diffraction dissociation contributions.

SUBROUTINE ABSRAT
Establishes the absolute production rate.
SUBROUTINE VEGAS(FXN,AVGI,SD,CHI2A)
Perform multidimensional Monte Carlo integration [21].

DOUBLE PRECISION FUNCTION RANDOM(SEED)
Random number generator [22].

SUBROUTINE WRIOUT(hwgt)
A user supplied routine to manage output information. hwgt is the correctly normalized weight that reproduces the physical cross section [3] when is summed over all the generated events.

3.3 Common blocks

COMMON/INPUT/beam1,beam2,hadron (All are CHARACTER*6 names)
beam1 1st beam particle type (defined by the User).
beam2 2nd beam particle type (defined by the User).
hadron The produced hadron type (defined by the User).

COMMON/BEAMS/beam1,beam2,hadron (All are CHARACTER*6 names)
beam1 1st beam particle type (for internall use).
beam2 2nd beam particle type (for internall use).
hadron The produced hadron type (for internall use).

COMMON/ATOMN/Atom1(2),Atom2(2)
Atom1(1) Atomic number of the 1st beam (if nucleus).
Atom1(2) Atomic weight of the 1st beam (if nucleus).
Atom2(1) Atomic number of the 2nd beam (if nucleus).
Atom2(2) Atomic weight of the 2nd beam (if nucleus).

COMMON/EXCIT/Level
The outgoing hadron excitation level, Level=0 is the ground state.

COMMON/VDMES/M1(3),M2(3)
The keys that switch on and off the vector meson component in a photon. M1(i) and M2(i) refer to the 1st and the 2nd beams, respectively, and i=1,2,3 stand for $\rho$, $\phi$ and $J/\psi$ meson contributions.

COMMON/KINEM/sqs,x1,x2,xF,y,hmass,pt2
sqs Total c.m.s. energy, $\sqrt{s}$ [GeV].
x1 Parton momentum fraction in the 1st beam, $x_{+}$
x2 Parton momentum fraction in the 2nd beam, $x_{-}$
xF Feynman variable of the produced hadron, $x_{F}$.
y Rapidity of the produced hadron, $y$.
hmass Mass of the produced hadron, $m_{H}$ [GeV].
pt2 Transverse momentum squared, $p_{T}^{2}$ [GeV$^{2}$].

COMMON/STRNG/n,nmax
The number of Pomerons exchanged and the maximal number of Pomerons

COMMON/POMER/Coeff,Gammp,Rpom2,AlPom,Delta
Coeff = 1.5 $C = 1 + \sigma_{DD}/\sigma_{el}$, equ.[1]
Gammp = 3.64 Pomeron residue parameter, $\gamma_{P}$ [GeV$^{-2}$]
Rpom2 = 3.56 Pomeron size parameter, $R^{2}$ [GeV$^{-2}$]
AlPom = 0.25 Pomeron trajectory slope, $\alpha'_{P}$ [GeV$^{-2}$]
Delta = 0.07 Pomeron intercept criticality, $\Delta$
The above parameters are fixed in the model and are not recommended to be altered.

COMMON/CXPOM/CXN(0:NP)
The multipomeron exchange cross sections $\sigma_D$, $\sigma_n$.

COMMON/REGGE/alp,aR,aJ,aN,aD,aV,aX,aO,aE
The intercept parameters for Reggeon, $\rho$, $\varphi$, $J/\psi$, $N$, $\Delta$, $\Lambda$, $\Xi$, $\Omega$ trajectories. Please note that the parameters $a_N$, $a_D$, $a_V$, $a_X$, $a_0$ must not be literally copied from Particle Data. They do not have actual meaning of baryon intercepts, but only enter the model in artificial combinations that correspond to fictitious trajectories of multiquark hybrid states. $a_E$ is the effective intercept shift for excited states (a model).

COMMON/TRNSV/gamh,gamr
Transverse momentum distribution parameters $\gamma^h$ and $\rho$, see equ. (12).

COMMON/STRAN/Snucl,Cnucl
Strange and Charm sea suppression parameters.

COMMON/PIPHI/Cpi,Cph,Cps
Fragmentation parameters for $\pi$ and $\phi$ mesons. Note that only the associated production of the type $\phi K \bar{K}$ is considered for $\phi$ mesons. The OZI-violating nonplanar diagrams are not included at present.

COMMON/PNLAM/Cn1,Cn2,C11,C12
Fragmentation parameters for $p$, $n$ and $\Lambda$.

COMMON/KAONS/Ck,Cks,Ck1,Ck2
Fragmentation parameters for Kaons.

COMMON/HYPER/Cs1,Cs2,Cx1,Cx2,Co1,Co2
Fragmentation parameters for $\Sigma$, $\Xi$ and $\Omega$ hyperons.

COMMON/CHARM/Cd,Cd1,Cd2,Cc1,Cc2,Cf,Cfs,Cfc,Cj,Cjc
Fragmentation parameters for $D$, $D_s$, $J/\psi$ mesons and $\Lambda_c$ baryon. Note that only the associated production of the type $J/\psi DD$ is considered for $J/\psi$ mesons. The OZI-violating nonplanar diagrams are not included at present.

COMMON/SUPER/Cxc,Cxcl,Cxc2
Fragmentation parameters for $\Xi_c$ baryons.

COMMON/VDPAR/VDM(3)
Photon to vector meson coupling constants, $4\pi\alpha/f_V^2$.

COMMON/RATES/rrho,reta,retap,romm,rexcit
Normalization parameters for hadron production rates.

COMMON/INDEX/ex,e1
The exponents that parameterize parton distributions.

COMMON/CNORM/CvalU(2,NP), CvalD(2,NP), CvalS(2,NP), CvalC(2,NP)
CbarU(2,NP), CbarD(2,NP), CbarS(2,NP), CbarC(2,NP)
CseaU(2,NP), CseaD(2,NP), CseaS(2,NP), CseaC(2,NP)
CvalUU(2,NP), CvalUD(2,NP), CvalDD(2,NP)
CvalUS(2,NP), CvalDS(2,NP), CvalSS(2,NP)
CbarUU(2,NP), CbarUD(2,NP), CbarDD(2,NP)
CbarUS(2,NP), CbarDS(2,NP), CbarSS(2,NP)
The normalization factors for parton distributions in the 1st and the 2nd beams, for an n-Pomeron exchange.
To run the program, the User has first to initiate the random number generator by the card \texttt{NUM=1}, to set the total c.m.s. energy and to specify the colliding beams and the hadron to be produced.

Also, the User has to define the lower \texttt{XL(i)} and the upper \texttt{XU(i)} limits for the independent variables that parametrize the phase space, i.e. \(\ln p_T^2\) and \(y\). (Note the use of logarithm of the transverse momentum.) The lower limit of the transverse momentum is an arbitrary small number (it should be only nonzero, to avoid formal arithmetical conflicts). The upper limit should be chosen in a reasonable agreement with the total c.m.s. energy \(s_{qs}\).

The wanted histograms have also to be booked in the \texttt{MAIN} program.

It is recommended to perform calculations in two steps. A short preliminary run optimizes the VEGAS grid to the integrand function shape:

\begin{verbatim}
NCALL = 1000    ! number of points per iteration
ITMX = 5        ! number of iterations
NPRN = 0        ! do not fill histograms
CALL VEGAS(FXN,AVGI,SD,CHI2A)
\end{verbatim}

After that one can start a long run to accumulate large statistics:

\begin{verbatim}
NCALL = 200000   ! number of points per iteration
ITMX = 1        ! number of iterations
NPRN = 1        ! do fill histograms
CALL VEGAS1(FXN,AVGI,SD,CHI2A)
\end{verbatim}

The quantity that is to be plotted in histograms for the physical cross section is given by \texttt{hwgt} (see \texttt{SUBROUTINE WRIOUT}).

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