MONCHER:
MONte Carlo generator for CHarge Exchange Reactions
Version 1.1

Physics and Manual

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Abstract
MONCHER is a Monte Carlo event generator for simulation of single and double charge exchange reactions in proton-proton collisions at energies from 0.9 to 14 TeV. Such reactions, $pp \rightarrow n + X$ and $pp \rightarrow n + X + n$, are characterized by leading neutron production. They are dominated by $\pi^+$ exchange and could provide us with more information about total and elastic $\pi^+ p$ and $\pi^+ \pi^+$ cross sections and parton distributions in pions in the still unexplored kinematical region.

Keywords
Single Charge Exchange – Double Charge Exchange – pion-proton – pion-pion – cross sections – event generator
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1 Introduction

In the paper we present a new Monte-Carlo event generator MONCHER. The generator is devoted to the simulation of single and double charge exchange reactions in proton-proton collisions at energies from 0.9 to 14 TeV. This region of energies covers the present capabilities of the LHC. Charge exchange reactions, $pp \rightarrow n + X$ and $pp \rightarrow n + X + n$, are characterized by the leading neutron production. They can be studied with LHC detectors incorporated with forward neutron calorimeters like the ZDC (Zero Degree Calorimeter) [1] in the CMS [2].

Reactions with the leading neutron production are dominated by $\pi^+\text{exchange}$ [3]-[6]. At the LHC they could provide us with information about $\pi^+p$ and $\pi^+\pi^+$ interactions in the region of energies 1-5 TeV in the c.m.s. Using indirect methods [7]-[8] we could extract total and elastic $\pi^+p$ and $\pi^+\pi^+$ cross sections at these energies. It is worth mentioning that the total cross-section of $\pi^+p$ interaction is measured only at energies up to 25 GeV by direct methods in the fixed target experiments [9] and total and elastic cross sections of $\pi^+\pi^+$ interactions are extracted from the data at energies 1.5-18.4 GeV only (see Ref. [10]-[12]). Moreover, a study of charge exchange reactions with hard scattering $\pi^+p$ and $\pi^+\pi^+$ followed by dijet production at the LHC, could provide us with parton distributions in the pion in the unexplored kinematical domain. So, we had weighty motivations to develop a model and to create a generator for charge exchange simulation which could be used at high energies of the LHC.

An important point is that at high energies we have to take into account effects of soft rescattering which can be calculated as corrections to the Born approximation. In the calculations of such absorptive effects we use the Regge-eikonal approach [13]. For $\pi^+p$ and $\pi^+\pi^+$ interactions several models which predict different cross sections have been applied. In addition to the dominant $\pi^+$ exchange we have calculated contributions of two other important Reggeons, $\rho^+$ and $\omega^+$, to the charge exchange cross section [14] and implemented both Reggeons to the generation. PYTHIA 6.4 [15] is used as a basic generator for MONCHER. MONCHER has the same format of events, parameters and common blocks as PYTHIA. PYTHIASubroutines are used also for the simulation of $\pi^+p$ and $\pi^+\pi^+$ interactions and for the subsequent hadronization and decays.

2 Physics Overview

2.1 Single Pion Exchange

The diagram of the Single pion Exchange (S\pi\E) process $p + p \rightarrow n + X$ is presented in Fig. [1a]. The momenta are $p_1$, $p_2$, $p_n$, $p_X$ respectively. In the center-of-mass frame these can be represented as follows (boldface letters denote transverse momenta):

$$p_1 = \left(\frac{\sqrt{s}}{2}, \frac{\sqrt{s}}{2} \beta, 0\right), \quad p_2 = \left(\frac{\sqrt{s}}{2}, -\frac{\sqrt{s}}{2} \beta, 0\right).$$

(1)

With this notation, the momentum of the $\pi^+$ is

$$p_\pi = \left(\frac{\xi \sqrt{s}}{2} \beta^2 + \frac{t + m_p^2 - m_n^2}{2 \sqrt{s}}, \frac{\xi \sqrt{s}}{2} \beta, q\right),$$

(2)

and

$$p_n = p_1 - p_\pi,$$

(3)

$$p_X^2 = M^2,$$

(4)
Figure 1: Amplitudes of the processes: a) \( p + p \rightarrow n + X \) (S\( \pi \)E), b) \( p + p \rightarrow n + X + n \) (D\( \pi \)E). \( S \) and \( S_2 \) represent soft rescattering corrections.

\[
\xi = \frac{M^2 - m_n^2 - 2(t + m_p^2 - m_n^2)}{s\beta^2} \approx \frac{M^2}{s}, \tag{5}
\]

\[
-t = \frac{q^2 + \xi^2\beta^2 m_p^2 + (m_n^2 - m_p^2) \left( \xi\beta^2 - \frac{m_n^2 - m_p^2}{s} \right)}{1 - \xi\beta^2 + \frac{2(m_n^2 - m_p^2)}{s}} \approx \frac{q^2 + \xi^2 m_p^2}{1 - \xi}, \tag{6}
\]

\[
\beta = \sqrt{1 - \frac{4m_p^2}{s}}. \tag{7}
\]

As a Born approximation for \( \pi \) exchange we use the familiar triple-Regge formula. This formula can be rewritten as

\[
\frac{d\sigma_{X,S\pi E}}{d\xi dt d\Phi_X} = \frac{G_{\pi^+pn}^2}{16\pi^2} \frac{-t}{(t - m_{\pi}^2)^2} F_0^2(t) \xi^{-1 - 2\alpha(\pi)}
\times \frac{d\sigma_{X,\pi^+p}(\xi s)}{d\Phi_X} S(s/s_0, \xi, t), \tag{8}
\]

where \( \Phi_X \) is the phase space for the system \( X \) produced in the \( \pi^+p \) scattering, the pion trajectory is \( \alpha_{\pi}(t) = \alpha'_\pi(t - m_{\pi}^2) \). The slope \( \alpha' \approx 0.9 \text{ GeV}^{-2} \), \( \xi = 1 - x_L \), where \( x_L \) is the fraction of the initial proton longitudinal momentum carried by the neutron, and \( G_{\pi^+pn}^2/(4\pi) = G_{\pi^+pn}^2/(8\pi) = 13.75 \) [16,17]. The form factor \( F_0(t) \) is usually expressed as an exponential

\[
F_0(t) = \exp(bt), \tag{9}
\]

where, from recent data [18,19], we expect \( b \approx 0.3 \text{ GeV}^{-2} \). We are interested in the kinematical range

\[
0.01 \text{ GeV}^2 < |t| < 0.5 \text{ GeV}^2, \xi < 0.4, \tag{10}
\]

where formula (8) dominates according to [20] and [21]. At high energies we can use any adequate parametrizations of different \( \pi^+p \) cross-sections.

### 2.1.1 Absorptive corrections

The suppression factor \( S \) arises from absorptive corrections [3]. We estimate absorption in the initial state for inclusive reactions and for both initial and final states in exclusive
exchanges. For this task we use our model with 3 Pomeron trajectories \[13\]:

\[
\begin{align*}
\alpha_{IP_1}(t) - 1 &= (0.0578 \pm 0.002) + (0.5596 \pm 0.0078)t, \\
\alpha_{IP_2}(t) - 1 &= (0.1669 \pm 0.0012) + (0.2733 \pm 0.0056)t, \\
\alpha_{IP_3}(t) - 1 &= (0.2032 \pm 0.0041) + (0.0937 \pm 0.0029)t.
\end{align*}
\]

These trajectories are the result of a 20 parameter fit of the total and differential cross-sections in the region

\[0.01 \text{ GeV}^2 < |t| < 14 \text{ GeV}^2, \quad 8 \text{ GeV} < \sqrt{s} < 1800 \text{ GeV}.\]

Although the \(\chi^2/d.o.f. = 2.74\) is rather large, the model gives good predictions for the elastic scattering (especially in the low-\(t\) region with \(\chi^2/d.o.f. \sim 1\)).

We use the procedure described in \[5, 6\] to estimate the absorptive corrections. With an effective factorized form of (see hereunder) expression \[12\] used for convenience, we obtain:

\[
\frac{\partial \sigma(s/s_0, \xi, \bq^2)}{\partial \xi d\bq^2} = S(s/s_0, \xi, \bq^2)\frac{\partial \sigma_0(\xi, \bq^2)}{\partial \xi d\bq^2},
\]

\[
\frac{\partial \sigma_0(\xi, \bq^2)}{\partial \xi d\bq^2} = \left(m_p\xi^2 + \bq^2\right) |\Phi_B(\xi, \bq^2)|^2 \frac{\xi}{(1 - \xi)^2} \sigma_{\pi p}(s/s),
\]

\[
S = \frac{m_p^2 \xi^2 |\Phi_0(s/s_0, \xi, \bq^2)|^2 + \bq^2 |\Phi_s(s/s_0, \xi, \bq^2)|^2}{(m_p^2 \xi^2 + \bq^2) |\Phi_B(\xi, \bq^2)|^2}.
\]

The functions \(\Phi_0\) and \(\Phi_s\) arise from different spin contributions to the amplitude

\[
A_{p \rightarrow n} = \frac{1}{\sqrt{1 - \xi}} \bar{\Psi}_n \left( m_p \xi \hat{\sigma}_3 \cdot \Phi_0 + \bq \hat{\sigma} \cdot \Phi_s \right) \Psi_p
\]

and both are equal to \(\Phi_B\) in the Born approximation. Here \(\hat{\sigma}_i\) are Pauli matrices and \(\bar{\Psi}_n, \Psi_p\) are neutron and proton spinors. All the above functions can be calculated by the following set of formulae:

\[
\Phi_B(\xi, \bq^2) = \frac{N(\xi)}{2\pi} \left( \frac{1}{\bq^2 + \epsilon^2} + \frac{i \pi \alpha_p'}{2(1 - \xi)} \right) \exp(-\beta^2 \bq^2) \simeq
\]

\[
\frac{N(\xi)}{2\pi} \frac{1}{\bq^2 + \epsilon^2 + \beta^2 \bq^2}, \quad \bq \rightarrow 0,
\]

\[
N(\xi) = (1 - \xi) \frac{G_{\pi^+p\pi^0}}{2} \frac{\alpha_p' \epsilon^2}{\xi (1 - \xi)} \exp \left[ -b \frac{m_p^2 \xi^2}{1 - \xi} \right],
\]

\[
\beta^2 = \frac{b + \alpha_p' \ln \frac{1}{\xi}}{1 - \xi}, \quad \epsilon^2 = m_p^2 \xi^2 + m_n^2 (1 - \xi),
\]

\[
\Theta_0(b, \xi, |\bq|) = \frac{b J_0(b|\bq|)}{1 - \beta^2 \epsilon^2} \left( K_0(\epsilon b) - K_0(\frac{b}{\beta}) \right),
\]

\[
\Theta_s(b, \xi, |\bq|) = \frac{b J_1(b|\bq|)}{1 - \beta^2 \epsilon^2} \left( \epsilon K_1(\epsilon b) - \frac{1}{\beta} K_1(\frac{b}{\beta}) \right),
\]

\[
\Phi_0 = \frac{N(\xi)}{2\pi} \int_0^{\infty} db \Theta_0(b, \xi, |\bq|) V(b),
\]

\[
|\bq| \Phi_s = \frac{N(\xi)}{2\pi} \int_0^{\infty} db \Theta_s(b, \xi, |\bq|) V(b),
\]
Table 1: Parameters of the model.

| i | $c_i$ | 1  | 2  | 3  |
|---|---|---|---|---|
| $r_i^2$ (GeV$^{-2}$) | 6.3096 ± 0.2522 | 3.1097 ± 0.1817 | 2.4771 ± 0.0964 |

The values of parameters $c_i$ and $r_i^2$ are derived in (11) and listed in Table 1. Figs. 2 demonstrate function $S(s/s_0, \xi, q_t^2)$ calculated for two values of energies a) $\sqrt{s} = 62.7$ GeV and b) $\sqrt{s} = 10$ TeV for different $\xi$ values: $\xi = 0.3$ (dotted), $\xi = 0.1$ (dashed) and $\xi = 10^{-4}$ (solid).

2.1.2 Parametrization of $\pi^+p$ cross section

In the present version of generator we use 4 parametrizations for $\pi^+p$ cross section.

The Donnachie-Landshoff (DL) parametrization [22]:

$$
\sigma_{\pi^+p}^{\text{tot}}(s) = 13.63 \ s^{0.0808} + 25.56 \ s^{-0.4525}, \text{ (mb)}.
$$

The COMPETE parametrization [23]:

$$
\sigma_{\pi^+p}^{\text{tot}}(s) = Z_{\pi p} + B \ln^2 \left( \frac{s}{s_0} \right) + (Y^{s^+} - Y^{s^0}) / s, \text{ (mb)}.
$$
Table 2: Parameters of the model [24].

| $c$  | $c'$ | $m_1$   | $m_2$   | $m_{3\pi}$ | $f_\pi$ | $a_\pi$ | $f$      | $a$      |
|------|------|---------|---------|------------|---------|---------|----------|---------|
| 0.167| 0.748| 0.577225| 1.719896| 0.7665     | 4.2414  | 2.3272  | 6.970913 | 1.858442|

$Z_{\pi p} = 21.23 \pm 0.33$ mb,  
$B = 0.3152 \pm 0.0095$ mb,  
$s_0 = 34 \pm 5.4$ GeV$^2$,  
$Y_+ = 17.8 \pm 1.10$, $\alpha_+ = 0.533 \pm 0.015$,  
$Y_- = 5.72 \pm 0.16$, $\alpha_- = 0.4602 \pm 0.0064$.

In the next two parametrizations total cross-section can be obtained thorough the optical theorem

$$\sigma_{\pi^+ p}^{\text{tot}} = \frac{1}{s} 3m \left. T(s, t) \right|_{t=0}.$$  \hspace{1cm} (29)

The Bourrely-Soffer-Wu (BSW) parametrization [24]:

$$T(s, t_p) = i \int_0^\infty b \, db \, J_0(b \sqrt{-t_p}) (1 - e^{-\Omega_0(s, b)}) ,$$  \hspace{1cm} (30)

$$\Omega_0(s, b) = \Omega_{IP} + \sum_i \Omega_i ,$$  \hspace{1cm} (31)

$$\Omega_{IP} \simeq \frac{s}{\ln s} \left[ 1 + \frac{\exp(c \sqrt{-t})}{\left( 1 + \frac{\pi}{\ln s} \right)^c} \right] F_{\text{BSW}}(b) \text{ for } s \gg m_p^2, |t|. \hspace{1cm} (32)$$

For the $\pi^+ p$ we have $i = \rho$ in (31) and

$$F_{\text{BSW}}^{\pi^+ p}(b) = \int_0^\infty q \, dq \, J_0(qb) f_\pi \frac{a^2 - q^2}{a^2 + q^2} \times \frac{1}{(1 + \frac{q^2}{m_2^2})(1 + \frac{q^2}{m_2^2})(1 + \frac{q^2}{m_{3\pi}^2})},$$  \hspace{1cm} (33)

$$\Omega_\rho \simeq C_\rho (1 + t) \left( \frac{s}{s_0} \right)^{\alpha_\rho(0)-1} e^{-\frac{s^2}{2B_\rho}}, \hspace{1cm} (34)$$

$$B_\rho = b_\rho + \alpha'_\rho(0) \ln \frac{s}{s_0}, \enspace b_\rho = 4.2704, \hspace{1cm} (35)$$

$$\alpha_\rho(t) = 0.3202 + t, \enspace C_\rho = 4.1624, \hspace{1cm} (36)$$

where values of parameters are listed in Table 2.

The Godizov-Petrov (GP) parametrization [25], [26].

In this parametrization the scattering amplitude is represented in the usual eikonal form

$$T(s, b) = \frac{e^{2i\delta(s, b)} - 1}{2i} \hspace{1cm} (37)$$

(here $T(s, b)$ is the amplitude in the impact parameter $b$ space, $s$ is the invariant mass squared of colliding particles and $\delta(s, b)$ is the eikonal function). Amplitudes in the impact parameter space and momentum one are related thorough the Fourier-Bessel transforms

$$f(s, b) = \frac{1}{16\pi s} \int_0^\infty d(-t) J_0(b \sqrt{-t}) f(s, t) , \hspace{1cm} (38)$$

$$f(s, t) = 4\pi s \int_0^\infty db^2 J_0(b \sqrt{-t}) f(s, b) . \hspace{1cm} (39)$$
Eikonal function in the momentum space is
\[ \delta(s, t) = \delta_p(s, t) + \delta_f(s, t) = \]
\[ = \left( i + \tan \frac{\pi (\alpha_p(t) - 1)}{2} \right) \beta_p(t) \left( \frac{s}{s_0} \right)^{\alpha_p(t)} + \]
\[ + \left( i + \tan \frac{\pi (\alpha_f(t) - 1)}{2} \right) \beta_f(t) \left( \frac{s}{s_0} \right)^{\alpha_f(t)}. \] (40)

The parametrization for the pomeron residue is
\[ \beta_p(t) = B_p e^{b_p t} (1 + d_1 t + d_2 t^2 + d_3 t^3 + d_4 t^4), \] (41)
which is approximately (at low values of \( d_1, d_2, d_3, d_4 \)) an exponential at low \( t \) values. Residues of secondary reggeons we set as exponentials:
\[ \beta_f(t) = B_f e^{b_f t}. \] (42)

| Pomeron | \( f_2 \)-reggeon | \( \omega \)-reggeon |
|-----------------|-----------------|-----------------|
| \( p_1 \) | 0.123 | \( c_f \) | 0.1 GeV² |
| \( p_2 \) | 1.58 GeV⁻² | \( B_f \) | 153 |
| \( p_3 \) | 0.15 | \( b_f \) | 4.7 GeV⁻² |
| \( B_P \) | 43.5 | \( B_\omega \) | 46 |
| \( b_P \) | 2.4 GeV⁻² | \( b_\omega \) | 5.6 GeV⁻² |
| \( d_1 \) | 0.43 GeV⁻² | \( \alpha_f(0) \) | 0.78 |
| \( d_2 \) | 0.39 GeV⁻⁴ | \( \alpha_f'(0) \) | 0.63 GeV⁻² |
| \( d_3 \) | 0.051 GeV⁻⁶ | \( \alpha_\omega(0) \) | 0.64 |
| \( d_4 \) | 0.035 GeV⁻⁸ | \( \alpha_\omega'(0) \) | 0.07 GeV⁻² |

Table 3: Values of parameters of the model [25, 26] for pp scattering.

Phenomenological parametrization for the "soft" pomeron trajectory is set to
\[ \alpha_p(t) = 1 + p_1 \left[ 1 - p_2 t \left( \arctg(p_3 - p_2 t) - \frac{\pi}{2} \right) \right]. \] (43)

Trajectories of secondary reggeons \( f_2 \) and \( \omega \) are parametrized by functions
\[ \alpha_R(t) = \left( \frac{8}{3\pi} \alpha_s(\sqrt{-t + c_R}) \right)^{1/2}, \quad R = f, \omega, \] (44)
where
\[ \alpha_s(\mu) = \frac{4\pi}{11 - \frac{2}{3} n_\text{f}} \left( \frac{1}{\ln \frac{\mu^2}{\Lambda^2}} + \frac{1}{1 - \frac{4\mu^2}{\Lambda^2}} \right) \] (45)
is the one-loop analytic QCD running coupling [27], \( n_f = 3 \) is the number of flavours, \( \Lambda \equiv \Lambda^{(3)} = 0.346 \text{ GeV} \) [28]. Parameters \( c_f \), \( c_\omega > 0 \) are rather small to spoil the asymptotic behaviour of secondary trajectories in the perturbative domain. Residues for \( \pi\pi \), \( \pi p \) and \( pp \) are assumed to be
\[ \beta_{\pi \pi}^p(t) = \frac{\beta_{\pi \pi}^{pp}(t) \beta_{\pi p}^{pp}(t)}{\beta_{\pi p}^{pp}(t)}, \] (46)
\[ \beta_{\pi \pi}^f(t) = \frac{\beta_{\pi \pi}^{fp}(t) \beta_{\pi p}^{fp}(t)}{\beta_{\pi p}^{fp}(t)}. \] (47)

Parameters of the model are listed in Tables 3.
2.2 Double Pion Exchange

The diagram of the Double Pion Exchange (DπE) process $p + p \rightarrow n + X + n$ is presented in Fig. 1b. The momenta are $p_1$, $p_2$, $p_n$, $p_X$, $p_{n_2}$ respectively. In the center-of-mass frame these can be represented as follows

$$p_{\pi_i} \simeq \left( \xi_i \frac{\sqrt{s}}{2}, (-1)^i \xi_i \frac{\sqrt{s}}{2}, q_i \right).$$

(48)

$$p_n i = p_i - p_{\pi_i},$$

(49)

$$p^2_X = M^2 = \xi_1 \xi_2 s \beta^2 \left( \frac{1 + \beta^2}{2} - (q_1 + q_2)^2 - m_p^2 \beta^2 (\xi_1^2 + \xi_2^2) + (t_1 + t_2 + 2(m_p^2 - m_n^2)) \left( \beta^2 (\xi_1 + \xi_2) + \frac{t_1 + t_2 + 2(m_p^2 - m_n^2)}{s} \right) \right) \simeq \xi_1 \xi_2$$

(50)

$$-t_i \simeq \frac{q_i^2 + \xi_i m_p^2}{1 - \xi_i}.$$ 

(51)

The cross-section can be evaluated as follows:

$$d\sigma = S_2(s/s_0, \xi_{1,2}, q_{1,2}^2) d\sigma_0,$$

(52)

$$\frac{d\sigma_0(\xi_1, \xi_2, q_1^2, q_2^2)}{d\xi_1 d\xi_2 dq_1^2 dq_2^2} = \prod_{i=1}^2 \left( \frac{m_p^2 \xi_i^2 + q_i^2}{|\Phi_B(\xi_i, q_i^2)|^2} \cdot \frac{\xi_i}{(1 - \xi_i)^2} \right) \cdot \sigma_{\pi^+ \pi^+}(\xi_1 \xi_2 s),$$

(53)

$$S_2 = \sum_{i,j=0,s} \prod_{i=1}^2 \left( \frac{m_p^2 \xi_i^2 + q_i^2}{|\Phi_B(\xi_i, q_i^2)|^2} \right)$$

(54)

$$\Phi_{ij} = \frac{N(\xi_1) N(\xi_2)}{(2\pi)^2}, \int_0^\infty \int_0^\infty \cos \phi (b_1^2 + b_2^2 - 2b_1 b_2 \cos \phi),$$

(55)

$$I_\phi (b_1, b_2) = \int_0^\pi \frac{d\phi}{\pi} \left( V \sqrt{b_1^2 + b_2^2 - 2b_1 b_2 \cos \phi} \right),$$

(56)

$$\rho_{00} = m_p^2 \xi_1 \xi_2, \quad \rho_{0s} = m_p \xi_1, \quad \rho_{s0} = m_p \xi_2, \quad \rho_{ss} = 1.$$ 

(57)

For low $t_i$ the function $S_2$ is approximately equal to

$$F(\xi_1, \xi_2) \equiv S_2(s/s_0, \xi_1, \xi_2, 0, 0) \simeq$$

$$\simeq \left( \sqrt{S(s/s_0, \xi_1, 0)} + \sqrt{S(s/s_0, \xi_2, 0)} - \sqrt{S(s/s_0, \xi_1, 0)S(s/s_0, \xi_2, 0)} \right)^2.$$ 

(58)

Figs. 3 demonstrates 2D projections of function $S_2(s/s_0, \xi_{1,2}, |q_{1,2}|)$ and function $F(\xi_1, \xi_2)$ at $\sqrt{s} = 10$ TeV.

To obtain $\pi^+ \pi^+$ cross-sections we use parametrizations described in the subsection 2.1.2 with the following approximations:

$$\sigma_{\pi^+ \pi^+}^{tot} \simeq \frac{(\sigma_{\pi^+ \pi^+}^{tot})^2}{\sigma_{pp}^{tot}},$$

(59)

for the DL and COMPETE ones, quantities

$$F_{BSW}^{\pi^+ \pi^+}(b) \simeq \int_0^\infty \int_0^\infty J_0(qb) \left( f_{\pi^+ \pi^+} \frac{a_{\pi^+ \pi^+}^2 - q^2}{a_{\pi^+ \pi^+}^2 + q^2} \frac{1}{1 + \frac{q^2}{m_{\pi^+}^2}} \right).$$

(60)
\( \Omega_0 \approx \Omega_{IP}, \quad f_{\pi \pi} = \frac{f_\pi^2}{f}, \quad \frac{1}{a_{\pi \pi}^2} = \frac{2}{a_\rho^2} - \frac{1}{a^2}, \) \tag{61}

for the BSW one, which should be substituted to \([32]\), and equations \([46],[47]\) for the GP one.

### 2.3 Relative contributions of \( \pi, \rho \) and \( a_2 \) reggeons.

For \( \rho \) and \( a_2 \) contributions formulae are similar to ones described in the chapters \([2,1]\) and \([2,2]\).

\[
\frac{d\sigma_{\text{SRE}}}{d\xi dt} = F_{R}(\xi, t)S_{R}(s/s_0, \xi, t) \sigma_{R+p}(\xi s), \tag{62}
\]

\[
\frac{d\sigma_{\text{DRSRE}}}{d\xi_1 d\xi_2 dt_1 dt_2} = F_{R\pi}(\xi_1, \xi_2, t_1, t_2)S_{R,2}(s/s_0, \{\xi_i\}, \{t_i\}) \times \sigma_{R+\pi}(\xi_1 \xi_2 s), \tag{63}
\]

\[
F_{R}(\xi, t) = \frac{|I_{R}(1)|^2 G_{R+p}^2}{16\pi^2} \exp\left(-2\kappa_{R}(t) \xi - 2\alpha_{R}(t)\right) \left(1 + \kappa_{R}^2 \frac{q^2}{4m_p^2}\right), \tag{64}
\]

\[
F_{R\pi}(\{\xi_i\}, \{t_i\}) = F_0(1)F_{R}(2) + F_0(2)F_{R}(1) + \]

\[
+2 \sqrt{\frac{F_0(1)F_0(2)F_{R}(1)F_{R}(2)}{t_1t_2(1-\xi_1)(1-\xi_2)}} \times \frac{\left(m_p\xi_1 + q_1^2 \frac{\kappa_{R}}{2m_p}\right) \left(m_p\xi_2 + q_2^2 \frac{\kappa_{R}}{2m_p}\right)}{\left(1 + q_1^2 \frac{\kappa_{R}}{4m_p^2}\right) \left(1 + q_2^2 \frac{\kappa_{R}}{4m_p^2}\right)}. \tag{65}
\]

\[
F_{0,R}(i) = F_{0,R}(\xi_i, t_i), \quad q_i^2 \simeq -t_i(1-\xi_i) - m_p^2 \xi_i^2. \tag{66}
\]

Here \( \kappa_{R} = 8 \) is the ratio of spin-flip to nonflip amplitude, \( \alpha_{R}(t) \simeq 0.5 + 0.9t \) and parameters for \( \rho, a_2 \) mesons are \([29]\)

\[
\eta_\rho = -i + 1, \quad \eta_{a_2} = i + 1, \tag{67}
\]

\[
b_\rho = 2 \text{ GeV}^{-2}, \quad b_{a_2} = 1 \text{ GeV}^{-2}, \tag{68}
\]

\[
\frac{G_{\rho+p}^2}{8\pi} = 0.18 \text{ GeV}^{-2}, \quad \frac{G_{a_2+p}^2}{8\pi} = 0.405 \text{ GeV}^{-2}. \tag{69}
\]

Rescattering corrections \( S_{R} \) and \( S_{R,2} \) are calculated by the method used in \([7],[8]\). Basic assumptions in our calculations are:

- \( \rho \rho, \rho a_2 \) and \( a_2 a_2 \) contributions are small;
interference terms of the type $T_{S\pi E}^* T_{S\pi E}$, $T_{DR\pi E}^* T_{DR\pi E}$ are small \[19\], $R, R' = \pi, \rho, a_2$, $R \neq R'$, where $T$ are amplitudes of the corresponding processes;

approximate relations $\sigma_{R+p} \simeq \sigma_{\pi+p}$, $\sigma_{R+\pi+} \simeq \sigma_{\pi+\pi+}$ \[19\].

Figs. 4 demonstrates 3D plots for cross sections of the Single and Double Reggeon Exchange reactions for the different reggeons ($S\pi E$ a), $S\rho E+S a_2 E$ b), $D\pi E$ c) and $D\rho\pi E+D a_2 \pi E$ d) at $\sqrt{s} = 7$ TeV.

![3D plots for cross sections](image)

Figure 4: Cross-sections $\frac{d\sigma}{d\xi dr}$ in $mb \cdot cm^{-1}$ at $\sqrt{s} = 7$ TeV for: a) $S\pi E$; b) $S\rho E+S a_2 E$; c) $D\pi E$; d) $D\rho\pi E+D a_2 \pi E$. $r$ is the transverse distance from the beam.
3 Program Overview

The kinematics of SI RE and DI RE reactions,

\[ pp \rightarrow n + (\text{IR}) \rightarrow n + X \]  \hspace{1cm} (70)

and

\[ pp \rightarrow n + (\text{IRIR}) + n \rightarrow n + X + n, \]  \hspace{1cm} (71)

are defined by the relative energy loss of \( \xi_n \) and the square of the transverse momentum \( t_n \) of the leading neutron. The vertex \( p_{IR}n \) is generated on the basis of the models described above. The differential cross sections for the generated neutron and reggeon are calculated according the selected models for absorptive corrections and for \( \text{IRp} (\text{IRIR}) \) interactions. Then, PYTHIA 6.420 \cite{15} is called for the \( \text{IRp} \rightarrow X \) generation in the case of SI RE and \( \text{IRIR} \rightarrow X \) generation in the case of DI RE. Parameters of the all generated particles, including beam protons, leading neutrons, reggeons and X, products of \( \text{IRp} \) (\text{IRIR}) interaction, are stored in PYTHIA common blocks.

3.1 Main Subroutines

**SUBROUTINE MONINIT**

**Purpose:** to initialize the generation procedure. In particular,
- to show program title;
- to read control parameters from the file \texttt{moncher.par};
- to set default MONCHER parameters;
- to initialize PYTHIA;
- to initialize LHE format output.

**Status of call:** should be called obligatory, one time, in the beginning of the main program before calling of \texttt{MONEVEN}.

**Calling by:** main program

**Calling of:** \texttt{MONTITL}, \texttt{MONPARA}, \texttt{MONMBDF}, \texttt{MONUPIN}, \texttt{PYINIT}

**SUBROUTINE MONTITL**

**Purpose:** to print title of MONCHER on the screen. Namely,

```
* **********************************************************
* MON-te-carlo generator for CH-arge E-xchange R-eactions
* Version 1.1.0.(12/03/2011)
* R.Ryutin,A.Sobol,V.Petrov (IHEP,Protvino)
* **********************************************************
```

**Status of call:** should be called OBLIGATORY.

**Calling by:** \texttt{MONINIT}
SUBROUTINE MONPARA

Purpose: to read control parameters for the MONCHER and PYTHIA generation from the file moncher.par Control parameters for MONCHER are called MONPAR, they are stored to the common block /MONGLPA/. Any PYTHIA parameters can be defined for PYTHIA common blocks /PYJETS/, /PYDAT1/, /PYDAT2/, /PYDAT3/, /PYDAT4/, /PYDATR/, /PYSUBS/, /PYPARS/, /PYINT1/, /PYINT2/, /PYINT3/, /PYINT4/, /PYINT5/, /PYINT6/, /PYINT7/, /PYINT8/, /PYMSSM/, /PYMSRV/, /PYTCSM/, /PYPUED/ (see [15]).

Status of call: can be called if you like to define some control parameters from the moncher.par. By default, MONCHER initializes a generation of minimum bias events by PYTHIA with some default parameters.

Calling by: MONINIT
Calling of: MONGIVE

SUBROUTINE MONMBDF

Purpose: to define default parameters for the generation. By default, MONCHER and PYTHIA parameters are defined to generate 10 minimum bias events at c.m.s. energy 7 TeV.

Status of call: to be called at initialization. Default parameters are redefined by the call of the MONPARA reading parameters from the file moncher.par.

Calling by: MONINIT
Calling of: MONGIVE

SUBROUTINE MONEVEN

Purpose: call subroutines for the single event generation

MONPAR(7)= 1 : call MONSPEG for Single Charge Exchange (SCE) generation.
MONPAR(8)= 1 : call MONDPEG for Double Charge Exchange (DCE) generation.
MONPAR(7)= 0 and MONPAR(8)= 0 : call PYEVNT for the PYTHIA event generation.

Status of call: should be called in the user main program, in the cycle of events.

Calling by: main program
Calling of: MONSPEG, MONDPEG, PYEVNT

SUBROUTINE MONSPEG

Purpose: to generate single SCE event, \( p_{beam}^{beam} p_{2}^{beam} \rightarrow n(\pi^{+}\pi^{0}_{virt}) \rightarrow nX \), in the following sequence:
- the vertex \( p_{1}^{beam} n \pi^{+} \) is generated by MONSPEM;
- PYTHIA is initialized for the generation of \( \pi^{+} p_{2}^{beam} \) interaction;
- PYTHIA is called for the generation, hadronization and decays;
- the PYTHIA output is rewriting to include beam protons and neutron to the final state of the reaction with the particles from X.

Simulation of \( \pi^{+} p_{2}^{beam} \) interaction is controlled by PYTHIA parameters. It can be elastic, minimum bias or diffractive interaction. Number of the corresponding SCE process is equal to the number of the PYTHIA process + 500.

Status of call: called if MONPAR(7)=1.

Calling by: MONEVEN
Calling of: MONSPEM, MONSHPY, PYINIT, PY1ENT, PYANGL
SUBROUTINE MONDPEG

Purpose: to generate single DCE event, $p_1^{beam} p_2^{beam} \rightarrow n(\pi^+_{\text{virt}} \pi^+_{\text{virt}})n \rightarrow nXn$, in the following sequence:
- the vertexes $p_1^{beam} n \pi^+_{\text{virt}}$ and $p_2^{beam} n \pi^+_{\text{virt}}$ are generated by MONDPEM;
- PYTHIA is initialized for the generation of $\pi^+_{\text{virt}} \pi^+_{\text{virt}}$ interaction;
- PYTHIA is called for the generation, hadronization and decays;
- the PYTHIA output is rewriting to include beam protons and neutrons to the final state of the reaction with the particles from X.
Simulation of $\pi^+_{\text{virt}} \pi^+_{\text{virt}}$ interaction is controlled by PYTHIA parameters. It can be elastic, minimum bias or diffractive interaction. Number of the corresponding DCE process is equal to the number of the PYTHIA process + 600.

Status of call: called if MONPAR(8)=1.
Calling by: MONEVEN
Calling of: MONDPEM, MONSHPY, PYINIT, PY1ENT, PYANGL

SUBROUTINE MONSPEM(NO,PN,PR,M2)

Purpose: to generate momentums and energies of neutron $n$ and virtual exchange reggeon $I R^+$ in the reaction of Single Charge Exchange:
$p_1^{beam} p_2^{beam} \rightarrow n(I R^+ + p_2^{beam}) \rightarrow nX$

INTEGER NO (input) : type of exchange reggeon $I R$;
= 1 : $\pi^+$
= 2 : $\rho^+$
= 3 : $a_2^+$

DOUBLE PRECISION PN(5) (output) : kinematical parameters of the neutron $n$.
PN(1) : $p_x$, momentum of neutron in the x direction, in GeV/c.
PN(2) : $p_y$, momentum of neutron in the y direction, in GeV/c.
PN(3) : $p_z$, momentum of neutron in the z direction, in GeV/c.
PN(4) : $E$, energy of neutron, in GeV.
PN(5) : $m$, mass of neutron, in GeV/c$^2$.

DOUBLE PRECISION PR(5) (output) : kinematical parameters of the reggeon $I R^+$.
PR(1) : $p_x$, momentum of reggeon in the x direction, in GeV/c.
PR(2) : $p_y$, momentum of reggeon in the y direction, in GeV/c.
PR(3) : $p_z$, momentum of reggeon in the z direction, in GeV/c.
PR(4) : $E$, energy of reggeon, in GeV.
PR(5) : $m$, mass of reggeon, in GeV/c$^2$.

DOUBLE PRECISION M2 (output) : invariant mass of the system $(I R^+ p_{beam2})$, in GeV/c$^2$.
Calling by: MONSPEG
Calling of: MONGE2D

SUBROUTINE MONDPEM(NO,PNI,PNI1,PNI2,PR1,PR2,M2)

Purpose: to generate momentums and energies of neutrons $n$ and virtual exchange reggeons $I R^+$ in the reaction of Double Charge Exchange:
$p_1^{beam} p_2^{beam} \rightarrow n(I R_1^+ I R_2^+)n \rightarrow nXn$

INTEGER NO (input) : type of exchange reggeons $I R_1^+ I R_2^+$;
= 1 : $\pi^+ \pi^+$
= 2 : $\pi^+ \rho^+$
= 3 : $\pi^+ a_2^+$

DOUBLE PRECISION PNI1(5), PNI2(5) (output) : kinematical parameters of the neutron $n$. 

Calling by: MONGE2D
Calling of: MONDPEM, MONSPEM, PYINIT, PY1ENT, SPAGL

SUBROUTINE MONSPEG

Purpose: to generate momentums and energies of neutron $n$ and virtual exchange reggeon $I R^+$ in the reaction of Single Charge Exchange:
$p_1^{beam} p_2^{beam} \rightarrow n(I R^+ + p_2^{beam}) \rightarrow nX$

INTEGER NO (input) : type of exchange reggeon $I R$;
= 1 : $\pi^+$
= 2 : $\rho^+$
= 3 : $a_2^+$

DOUBLE PRECISION PN(5) (output) : kinematical parameters of the neutron $n$.
PN(1) : $p_x$, momentum of neutron in the x direction, in GeV/c.
PN(2) : $p_y$, momentum of neutron in the y direction, in GeV/c.
PN(3) : $p_z$, momentum of neutron in the z direction, in GeV/c.
PN(4) : $E$, energy of neutron, in GeV.
PN(5) : $m$, mass of neutron, in GeV/c$^2$.

DOUBLE PRECISION PR(5) (output) : kinematical parameters of the reggeon $I R$.
PR(1) : $p_x$, momentum of reggeon in the x direction, in GeV/c.
PR(2) : $p_y$, momentum of reggeon in the y direction, in GeV/c.
PR(3) : $p_z$, momentum of reggeon in the z direction, in GeV/c.
PR(4) : $E$, energy of reggeon, in GeV.
PR(5) : $m$, mass of reggeon, in GeV/c$^2$.

DOUBLE PRECISION M2 (output) : invariant mass of the system $(I R^+ p_{beam2})$, in GeV/c$^2$.
Calling by: MONSPEM
Calling of: MONDPEM, MONSPEM, PYINIT, PY1ENT, SPAGL

SUBROUTINE MONDPEM(NO,PNI,PNI1,PNI2,PR1,PR2,M2)

Purpose: to generate momentums and energies of neutrons $n$ and virtual exchange reggeons $I R^+$ in the reaction of Double Charge Exchange:
$p_1^{beam} p_2^{beam} \rightarrow n(I R_1^+ I R_2^+)n \rightarrow nXn$

INTEGER NO (input) : type of exchange reggeons $I R_1^+ I R_2^+$;
= 1 : $\pi^+ \pi^+$
= 2 : $\pi^+ \rho^+$
= 3 : $\pi^+ a_2^+$

DOUBLE PRECISION PNI1(5), PNI2(5) (output) : kinematical parameters of the neutron $n$. 

Calling by: MONGE2D
Calling of: MONDPEM, MONSPEM, PYINIT, PY1ENT, SPAGL
tron $n$.

$PN1(1),PN2(1)$ : $p_x$, momentum of neutrons in the $x$ direction, in GeV/c.

$PN1(2),PN2(2)$ : $p_y$, momentum of neutrons in the $y$ direction, in GeV/c.

$PN1(3),PN2(3)$ : $p_z$, momentum of neutrons in the $z$ direction, in GeV/c.

$PN1(4),PN2(4)$ : $E$, energy of neutrons, in GeV.

$PN1(5),PN2(5)$ : $m$, mass of neutrons, in GeV/c$^2$.

DOUBLE PRECISION $PR1(5),PR2(5)$ (output) : kinematical parameters of the reggeons $R^+_1,R^+_2$.

$PR(1),PR2(1)$ : $p_x$, momentum of reggeons in the $x$ direction, in GeV/c.

$PR(2),PR2(2)$ : $p_y$, momentum of reggeons in the $y$ direction, in GeV/c.

$PR(3),PR2(3)$ : $p_z$, momentum of reggeons in the $z$ direction, in GeV/c.

$PR(4),PR2(4)$ : $E$, energy of reggeons, in GeV.

$PR(5),PR2(5)$ : $m$, mass of reggeons, in GeV/c$^2$.

DOUBLE PRECISION $M2$ (output) : invariant mass of the system $(R^+_1,R^+_2)$, in GeV/c$^2$.

Calling by: MONDPEG

Calling of: MONGE2D, MONGE2D4

---

**SUBROUTINE MONSHPY(NSHIFT)**

**Purpose:** to shift data of arrays of the Pythia common block /PYJETS/ for NSHIFT positions. It should be done to fill first NSHIFT positions of /PYJETS/ arrays by the parameters of the beam protons and neutrons in the final state of reaction.

Calling by: MONSPEG, MONDPEG

---

**SUBROUTINE MONGIVE(CHIN)**

**Purpose:** modification of the Pythia subroutine PYGIVE to set the value of any variable residing in the common blocks PYJETS, PYDAT1, PYDAT2, PYDAT3, PYDAT4, PYDATR, PYSUBS, PYPARS, PYINT1, PYINT2, PYINT3, PYINT4, PYINT5, PYINT6, PYINT7, PYINT8, PYMSSM, PYMSRV, PYTCSM or MONGLPA. This is done in a more controlled fashion than by directly including the common blocks in your program, in that array bounds are checked and the old and new values for the variable changed are written to the output for reference. In the following example, "CALL MONGIVE('MONPAR(3)=14000')", we have changed pp c.m.s. energy to 14 TeV. More detail explanation see in Ref. [15] for subroutine PYGIVE.

**CHARACTER CHIN**(100) (input) :** character expression of length at most 100 characters, with requests for variables to be changed.

Calling by: MONPARA, MONMBDF

---

**SUBROUTINE MONUPEV**

**Purpose:** to write information about generated processes to the file moncher.lhe using special LHE record format. For more detail information about LHE format see Ref. [30].

**Status of call:** called if MONPAR(2)=1.

Calling by: MONINIT

---

**SUBROUTINE MONUPIN**

**Purpose:** to save information about all stable particles generated in the event to the file
moncher.lhe using special LHE record format. For more detail information about LHE format see Ref. [30].

Status of call: should be called for each generated event if MONPAR(2)=1.
Calling by: user main program

3.2 Auxiliary Subroutines

These subroutines are used for internal calculations and should not be changed.

```fortran
SUBROUTINE MONGE2D(FF,X1,X2,N1,N2,FF1,FF2,FF3,RG,XG,IG)

Purpose: to generate two variables according to the 2D distribution from the table.
DOUBLE PRECISION FF(N1,N2) (input) : N1×N2 dimensional interpolation table of 2D distribution.
DOUBLE PRECISION X1(N1),X2(N2) (input) : arrays of variables corresponding to the table FF.
INTEGER N1,N2 (input) : dimensions of the 2D table.
DOUBLE PRECISION FF1(N1),FF2(N1) (input) : auxiliary integrated tables for 2D distribution.
DOUBLE PRECISION FF3(2,N1,N2) (input) : auxiliary sums from the table for 2D distribution.
DOUBLE PRECISION RG(2) (input) : array for generated random numbers from 0 to 1.
DOUBLE PRECISION XG(2) (output) : array for generated variables according to the 2D distribution.
INTEGER IG(2) (output) : auxiliary numbers of the nearest to the XG(2) discrete point.
Calling by: MONSPEM, MONDPEM
```

```fortran
SUBROUTINE MONG2D4(FF,X1,X2,N1,N2,FF1,FF2,FF3,II,XX,RG,XG)

Purpose: to generate four variables according to the 4D distribution from the table.
DOUBLE PRECISION FF(N1,N1,N2,N2) (input) : N1×N1×N2×N2 dimensional interpolation table of 4D distribution.
DOUBLE PRECISION X1(N1),X2(N2) (input) : arrays of variables corresponding to the table FF.
INTEGER N1,N2 (input) : dimensions of the 4D table.
DOUBLE PRECISION FF1(4,N1,N1,N2),FF2(4,N1,N1,N2) (input) : auxiliary integrated tables for the 4D distribution.
DOUBLE PRECISION FF3(8,N1,N1,N2,N2) (input) : auxiliary sums from the table for the 4D distribution.
INTEGER II(2) (input) : auxiliary numbers for multidimensional calculations.
DOUBLE PRECISION XX(2) (input) : auxiliary points for multidimensional calculations.
DOUBLE PRECISION RG(4) (input) : array for generated random numbers from 0 to 1.
DOUBLE PRECISION XG(4) (output) : array for generated variables according to the 4D distribution.
Calling by: MONDPEM
```

```fortran
SUBROUTINE MONCUBI(FF,VS,FUN)

Purpose: cubic spline interpolation for a function in the variable ln s.
DOUBLE PRECISION FF(6) (input) : table of the function at six values of variable s stored in the array XSQ(6) (see below the commonblock MONTAB1).
```
DOUBLE PRECISION VS(input) : input value of s.
DOUBLE PRECISION FUN(output) : output value of the function.
Calling by: MONDATA

SUBROUTINE MONLI2D(FDT,X1,X2,N1,N2,XV,FUN)

Purpose: Linear 2D interpolation from the table of any function.
DOUBLE PRECISION FDT(N1,N2)(input) : N1×N2 dimensional table of values for the input function.
DOUBLE PRECISION X1(N1),X2(N2)(input) : arrays for discrete points corresponding to the values of the input function.
INTEGER N1,N2(input) : dimensions of the 2D interpolation table.
DOUBLE PRECISION XV(2)(input) : input values for two variables of the function.
DOUBLE PRECISION FUN(output) : output value of the function.
Calling by: MONDATA

SUBROUTINE MONLI4D(FDT,X1,X2,X3,X4,N1,N2,N3,N4,XV,FUN)

Purpose: Linear 4D interpolation from the table of any function.
DOUBLE PRECISION FDT(N1,N2,N3,N4)(input) : N1×N2×N3×N4 dimensional table of values for the input function.
DOUBLE PRECISION X1(N1),X2(N2),X3(N3),X4(N4)(input) : arrays for discrete points corresponding to the values of the input function.
INTEGER N1,N2,N3,N4(input) : dimensions of the 4D interpolation table.
DOUBLE PRECISION XV(4)(input) : input values for four variables of the function.
DOUBLE PRECISION FUN(output) : output value of the function.
Calling by: MONDATA

SUBROUTINE MONIN2D(FF,X1,X2,N1,N2,FF1,FF2,FF3)

Purpose: calculations of additional integrated tables used in the generation subroutine MONGE2D,MONG2D4.
DOUBLE PRECISION FF(N1,N2)(input) : input table of 2D function.
DOUBLE PRECISION X1(N1),X2(N2)(input) : arrays for discrete points corresponding to the values of the input function.
INTEGER N1,N2(input) : dimensions of the 2D interpolation table.
DOUBLE PRECISION FF1(N1),FF2(N1),FF3(2,N1,N2)(output) : generated auxiliary tables.
Calling by: MONDATA, MONIN4D

SUBROUTINE MONIN4D(FF,X1,X2,N1,N2,FF1,FF2,FF3)

Purpose: calculations of additional integrated tables used in the generation subroutine MONG2D4.
DOUBLE PRECISION FF(N1,N1,N2,N2)(input) : input table of 4D function.
DOUBLE PRECISION X1(N1),X2(N2)(input) : arrays for discrete points corresponding to the values of the input function.
INTEGER N1,N2(input) : dimensions of the 4D interpolation table.
DOUBLE PRECISION FF1(2,N1,N2),FF2(2,N1,N1,N2),FF3(8,N1,N1,N2,N2)(output) : generated auxiliary tables.
SUBROUTINE MONDATA

Purpose: to read tables for absorptive corrections and for $pRn$ form factors from the external files $Spi_1$, $Sro_1$, $Sa2_1$, $S2pi_1$, $S2ro_1$, $S2a2_1$, $FFpi_1$, $FFro_1$, $FFa2_1$. These tables are used for calculation of the differential cross sections for SCE and DCE reactions at given energy (defined by parameter $MONPAR(3)$) by interpolation methods.

Status of call: is called if $MONPAR(7)=1$ or $MONPAR(8)=1$.

Calling by: MONINIT
Calling of: MONCUBI, MONLI2D, MONLI4D, MONIN2D, MONIN4D

3.3 Main Functions

DOUBLE PRECISION FUNCTION MONCSEC(KP,KR)

Purpose: to give the value of the total cross section of SCE ($pp \rightarrow nX$) or DCE ($pp \rightarrow nXn$) reaction for the given reggeon exchange at the c.m.s. energy defined by parameter $MONPAR(3)$ for the model defined by parameters $MONPAR(4)$ and $MONPAR(5)$.

INTEGER KP (input) : single or double exchange
  = 1 : for SCE cross section
  = 2 : for DCE cross section

INTEGER KR (input) : type of the reggeon exchange
  = 1 : for SCE define $\pi^+$ exchange, for DCE $\pi^+\pi^+$ one.
  = 2 : for SCE $\rho^+$ exchange, for DCE $\pi^+\rho^+$.
  = 3 : for SCE $a_2^+$ exchange, for DCE $\pi^+a_2^+$.

Calling by: MONINIT

DOUBLE PRECISION FUNCTION MONCSCe(NO,XI,QT)

Purpose: to give the value of cross section of SCE ($pp \rightarrow nX$) reaction for the given reggeon exchange at given $\xi_n$ of neutron and $Q_t$ of reggeon at the c.m.s. energy defined by parameter $MONPAR(3)$ for the model defined by parameters $MONPAR(4)$ and $MONPAR(5)$.

INTEGER NO (input) : type of the reggeon exchange
  = 1 : for $\pi^+$ exchange.
  = 2 : for $\rho^+$ exchange.
  = 3 : for $a_2^+$ exchange.

DOUBLE PRECISION XI (input) : $\xi_n = \frac{|p_{\text{beam}} - p_n|}{p_{\text{beam}}}$, relative momentum loss of the neutron.

DOUBLE PRECISION QT (input) : $Q_t$, transverse momentum of the exchange reggeon.

Calling by: MONCDCE, MONDATA

DOUBLE PRECISION FUNCTION MONCDCE(NO,XI1,XI2,QT1,QT2)
**Purpose:** to give the value of cross section of the DCE \((pp \rightarrow nXn)\) reaction for the given reggeon exchange at given \(\xi_{n}^{1,2}\) of neutron and \(Q_{t}^{1,2}\) of reggeons at the c.m.s. energy defined by parameter MONPAR(3) for the model defined by parameters MONPAR(4) and MONPAR(5).

**INTEGER NO (input):** type of the reggeon exchange  
- 1: for \(\pi^+\pi^+\) exchange.  
- 2: for \(\pi^+\rho^+\) exchange.  
- 3: for \(\pi^+a_2^+\) exchange.

**DOUBLE PRECISION XI (input):** \(\xi_{n}^{1,2} = \frac{|p_{n_{beam}}^{1,2} - p_n^{1,2}|}{p_{beam}^{1,2}}\), relative momentum loss of the neutrons.

**DOUBLE PRECISION QT (input):** \(Q_{t}^{1,2}\), transverse momentum of the exchange reggeons.

Calling by: MONCDCE, MONDATA

**DOUBLE PRECISION FUNCTION MONCSRP(NO,NCSMOD,SVAR)**

**Purpose:** to give the value of the total reggeon-proton cross section

**INTEGER NO (input):** type of the reggeon exchange  
- 1: for \(\pi^+\) exchange.  
- 2: for \(\rho^+\) exchange.  
- 3: for \(a_2^+\) exchange.

**INTEGER NCSMOD (input):** type of model for the reggeon-proton cross section calculation  
- 1: Donnachie-Landshoff parametrization [22].  
- 2: COMPETE parametrization [23].  
- 3: Bourrely-Soffer-Wu parametrization [24].  
- 4: Godizov-Petrov parametrization [25].

**DOUBLE PRECISION SVAR (input):** invariant mass of reggeon-proton system

Calling by: MONCSRR, MONCSCE, MONCDCE

**DOUBLE PRECISION FUNCTION MONCSRR(NO,NCSMOD,SVAR)**

**Purpose:** to give the value of the total reggeon-reggeon cross section

**INTEGER NO (input):** type of the reggeon-reggeon exchange  
- 1: for \(\pi^+\pi^+\) exchange.  
- 2: for \(\pi^+\rho^+\) exchange.  
- 3: for \(\pi^+a_2^+\) exchange.

**INTEGER NCSMOD (input):** type of model for the reggeon-reggeon cross section calculation  
- 1: Donnachie-Landshoff parametrization [22].  
- 2: COMPETE parametrization [23].  
- 3: Bourrely-Soffer-Wu parametrization [24].  
- 4: Godizov-Petrov parametrization [25].

**DOUBLE PRECISION SVAR (input):** invariant mass of reggeon-reggeon system

Calling by: MONDATA, MONCDCE
3.4 Main Commonblocks and Parameters

PARAMETER (MXGLPAR=200)
REAL MONPAR
COMMON/MONGLPX/ MONPAR(MXGLPAR)

Purpose: to give access to the main MONCHERS switches and parameters

MONPAR(1) : number of events for the generation.
MONPAR(2) : switch for LHE output.
    = 0 : LHE output is switched off.
    = 1 : LHE output is switched on.
MONPAR(3) : pp centre mass energy, in GeV, (from 900 to 14000 GeV).
MONPAR(4) : kod of model for pR and RR interaction.
    = 1 : Donnachie-Landshoff parametrization [22].
    = 2 : COMPETE parametrization [23].
    = 3 : Bourrely-Soffer-Wu parametrization [24].
    = 4 : Godizov-Petrov parametrization [25].
MONPAR(5) : kod of model for absorptive corrections.
    = 1 : 3 Pomerons eikonal model [13].
MONPAR(6) : type of exchange reggeon.
    = 1 : for SCE define $\pi^+$ exchange, for DCE $\pi^+\pi^+$ one.
    = 2 : for SCE $\rho^+$ exchange, for DCE $\pi^+\rho^+$. 
    = 3 : for SCE $a_2^+$ exchange, for DCE $\pi^+a_2^+$. 
MONPAR(7) : switch for SCE generation.
    = 0 : SCE is switched off.
    = 1 : SCE is switched on.
MONPAR(8) : switch for DCE generation.
    = 0 : DCE is switched off.
    = 1 : DCE is switched on.

Note 1: if MONPAR(7)=0 and MONPAR(8)=0, minimum bias events are generated by PYTHIA.

Note 2: in the present version of MONCHER, v.1.1, the simultaneous generation of SCE and DCE is impossible.

DOUBLE PRECISION S
INTEGER NMODPP,NMODRR,ITYPR
COMMON/MONTABO/S,NMODPP,NMODRR,ITYPR

Purpose: to give access to some important MONCHER parameters.

S : pp c.m.s. energy, in GeV.
NMODPP : kod of model for absorptive corrections.
    = 1 : 3 Pomerons eikonal model [13].
NMODRR : kod of model for pR and RR interaction.
    = 1 : Donnachie-Landshoff parametrization [22].
    = 2 : COMPETE parametrization [23].
    = 3 : Bourrely-Soffer-Wu parametrization [24].
    = 4 : Godizov-Petrov parametrization [25].
ITYPR : type of exchange reggeon.
    = 1 : for SCE define $\pi^+$ exchange, for DCE $\pi^+\pi^+$ one.


\[ = 2 : \text{for SCE } \rho^+ \text{ exchange, for DCE } \pi^+ \rho^+. \]

\[ = 3 : \text{for SCE } a_2^+ \text{ exchange, for DCE } \pi^+ a_2^+. \]

**Purpose:** to give access to some important **MONCHER** parameters.

**XSQ**:
- six values of \( \sqrt{s} \) for the interpolation subroutine **MONCUBI**.

**PI**:
- \( 3.141592653589793D0 \)

**MPI**:
- pion mass.

**MP**:
- proton mass.

**MN**:
- neutron mass.

**MRHO**:
- \( \rho \) meson mass.

**MA2**:
- \( a_2 \) meson mass.

**Purpose:** to give access to some important **MONCHER** parameters.

**XMIN**:
- minimal value of the variable \( \xi \).

**XMAX**:
- maximal value of the variable \( \xi \).

**QTMIN**:
- minimal value of the variable \( |q| \) (transverse momentum of the neutron).

**QTMAX**:
- maximal value of the variable \( |q| \) (transverse momentum of the neutron).

**Purpose:** to give access to some important **MONCHER** parameters.

**API**:
- slope of the pion regge trajectory.

**ARHO**:
- slope of the \( \rho \) meson regge trajectory.

**AA2**:
- slope of the \( a_2 \) meson regge trajectory.

**R2PI**:
- slope of the exponent in the residue of the pion trajectory.

**R2RHO**:
- slope of the exponent in the residue of the \( \rho \) meson trajectory.

**R2A2**:
- slope of the exponent in the residue of the \( a_2 \) meson trajectory.

**Purpose:** to give access to some important **MONCHER** parameters.

**GPI,GRHO,GA2**:
- constants \( G^2_{\pi pn}/(8\pi) \), \( \tilde{G}^2_{\rho pn}/(8\pi) \) and \( \tilde{G}^2_{a_2^+pn}/(8\pi) \).

**SIGRSQ**:
- \( |\eta_R|^2 \).

**KARHO, KAA2**:
- \( \kappa_\rho, \kappa_{a_2} \).
Purpose: to give access to the input tables.

Purpose: to give access to the additional tables obtained from the input files.

Purpose: to give access to the tables for 2D and 4D generations.

Purpose: to give access to the auxiliary tables for 2D and 4D generations.

Purpose: to give access to the auxiliary tables for 2D and 4D generations.
DOUBLE PRECISION VXIR, VFIS, VFIA, VQTR,
& VXIRF, VFIF, VXI, VQT, SVXI, SVQT, DVXI, DVQT
COMMON/MONDVAR/VXIR(10), VFIS(8), VFIA(8), VQTR(9),
& VXIRF(60), VFIF(16), VXI(53), VQT(41),
& SVXI(41), SVQT(41), DVXI(17), DVQT(17)

Purpose: to give access to the arrays of variables for the input and auxiliary tables.
4 Program Installation

Some materials related to the MONCHER physics and generator is the one found on the web page

http://rioutine.web.cern.ch/rioutine

in the section ”Generators”. To get the code of the generator one should download the file

http://rioutine.web.cern.ch/rioutine/gencode/moncher1.1.tar.gz

The program is written essentially entirely in standard Fortran 77, and should run on any platform with such a compiler.

The following installation procedure is suggested for the Linux users, it was tested with CERN SLC5.

$ gunzip moncher1.1.tar.gz
$ tar -cvf moncher1.1.tar
$ cd moncher/1.1.0
$ ls

Now you can see some files:

- README contains brief description of the files in the current directory;
- moncher.f is the code of the generator;
- moncher.par defines switch keys and parameters for the simulation;
-Spi_1 Sro_1 Sa2_1 contain data for the calculations of absorptive corrections for SCE;
- Sp2i_1 S2ro_1 S2a2_1 contain data for absorptive corrections for DCE;
- FFpi_1 FFro_1 FFa2_1 contain data for form-factors;
- mkmoncher is the executable file to compile and link moncher.f;
- rmoncher is the executable file to run moncher created by mkmoncher.

$ ./mkmoncher

compiles moncher.f by g77 compiler and link the generator with PYTHIA 6.420 [15] and some CERNLIB libraries. Then, created executable moncher should be run by

$ ./rmoncher

Result of the simulation should be the PYTHIA standard listing of one generated event of the SCE reaction $pp \rightarrow nX$ at c.m.s. energy 7 TeV. The listing should be printed on the screen. If you have passed successfully all above, get start with the next step.
5 Getting Started with the Simple Example

The Simple Example could look as following:

```fortran
PROGRAM MAIN
IMPLICIT DOUBLE PRECISION(A-H, O-Z)
IMPLICIT INTEGER(I-N)
c...global MONCHER parameters
INTEGER MXGLPAR
REAL MONPAR
PARAMETER (MXGLPAR=200)
COMMON/MONGLPA/ MONPAR(MXGLPAR)
c...initialization
CALL MONGIVE('MONPAR(1)=1000')  ! number of events
CALL MONGIVE('MONPAR(2)=1')    ! switch for LHE saving
CALL MONGIVE('MONPAR(3)=7000')  ! pp centre mass energy in GeV
CALL MONGIVE('MONPAR(4)=1')    ! code of model for pR/RR interaction
CALL MONGIVE('MONPAR(5)=1')    ! code of model for absorption
CALL MONGIVE('MONPAR(6)=1')    ! type of Reggeon
CALL MONGIVE('MONPAR(7)=1')    ! switch for SCE generation
CALL MONGIVE('MONPAR(8)=0')    ! switch for DCE generation
CALL MONGIVE('MSEL=2')        ! pythia: mb+sd+dd+elastic+lowpt
CALL MONINIT

NTOT=MONPAR(1)
KLHE=MONPAR(2)
c...generation
DO NEV=1,NTOT
   CALL MONEVEN
   IF(NEV.EQ.1) CALL PYLIST(1)
   CALL ANALYZER(IOUT)
   IF(KLHE.EQ.1.AND.IOUT.EQ.1) CALL MONUPEV
ENDDO
c...final statistics
CALL PYSTAT(1)
c...produce final Les Houches Event File.
   IF(KLHE.EQ.1) CALL PYLHEF

STOP
END
```

First, we set some values for elements of array MONPAR which control a process of generation. Then, we should initialize the generator calling MONINIT. In this example we are going to generate 1000 events of Single Pion Exchange, $pp \rightarrow n(\pi^+ p) \rightarrow nX$, at c.m.s. energy 7 TeV. The $(\pi^+ p)$ interaction is controlled by PyTHIA and it includes minimum bias, single and double diffraction, elastic scattering and low-pt scattering. Filling of MONPAR elements can be done also from the external file moncher.par. Subroutine MONPARA calling by MONINIT checks the presence of the moncher.par in the current directory and, if it exists, reads parameters MONPAR, see chapter 6.
On the next step, we generate some number of events, defined by \texttt{MONPAR(2)}. Every event is generated by \texttt{MONEVEN}. User's subroutine \texttt{ANALYZER(IOUT)} is called after every event generation, analyses the event and sets some value to the integer variable \texttt{IOUT}. If \texttt{IOUT} is equal to unity, we save this event in the LHE format using the subroutine \texttt{MONUPEV}.

Here you can see example of the Simple Analyzer:

```fortran
SUBROUTINE ANALYZER(IOUT)
IMPLICIT DOUBLE PRECISION(A-H, O-Z)
IMPLICIT INTEGER(I-N)
c...HEPEVT common block.
PARAMETER (NMXHEP=4000)
COMMON/HEPEVT/NEVHEP,NHEP,ISTHEP(NMXHEP),IDHEP(NMXHEP),
& JMOHEP(2,NMXHEP),JDAHEP(2,NMXHEP),PHEP(5,NMXHEP),VHEP(4,NMXHEP)
DOUBLE PRECISION PHEP,VHEP
SAVE /HEPEVT/

c IOUT =0
ISIGN =1
NEUTRONS=0
c
CALL PYHEPC(1)
c
DO I=1,NHEP
KP =IDHEP(I)
ETA =PYP(I,19)
IF(KP.EQ.2112.AND.DABS(ETA).GE.8.5) THEN
   NEUTRONS=NEUTRONS+1
   ISIGN=ISIGN*ETA
ENDIF
ENDDO
c
IF(NEUTRONS.EQ.2.AND.ISIGN.LT.0) IOUT=1
c
RETURN
END
```

In this example, we analyse all particles in the generated event and look for the neutrons (code 2112) in the region of pseudorapidity $|\eta| \geq 8.5$ (assumed acceptance of the neutron detector). If number of such neutrons is equal to 2 and they move in opposite directions, \texttt{IOUT} is set to unity.

Finally, we print the \texttt{PYTHIA} statistics by \texttt{PYSTAT} and produce the final LHE file which has the name \texttt{moncher.lhe} by default.

This example has a concrete physical meaning. We have selected SCE events with 2 leading neutrons moving in the opposite directions which imitate a DCE process. So, we have saved background for the DCE from the SCE.
6 Program Control Parameters

All parameters that control the generation can be defined in the external file moncher.par. For example, the set of parameters for the generation of the $S\pi E$ process, described in the chapter 5, can look as follows:

```
c--------------------- MONCHER v.1.1.0 card file

c----------------------------------------------- MONCHER control keys

c MONPAR(1)=1000 ! number of events to generate
  c
MONPAR(2)=1 ! key for Les Houches data (1-save, 0-no)
  c
MONPAR(3)=7000 ! pp centre mass energy in GeV (900 -> 14000)
  c
MONPAR(4)=1 ! code of model for pR and RR interaction
  c   NMODRR=1 -> Donnachie-Landshoff model (default)
  c   NMODRR=2 -> COMPETE (PDG) model
  c   NMODRR=3 -> Bourreli-Sopfer-Wu model
  c   NMODRR=4 -> Godizov-Petrov model
  c
MONPAR(5)=1 ! code of model for absorption
  c   NMODPP=1 3 IP eikonal model (default)
  c not now   NMODPP=2 -> Godizov-Petrov model
  c not now   NMODPP>2 -> other models...
  c
MONPAR(6)=1 ! type of Reggeon (1-$\pi^+$, 2-$\rho^+$, 3-$a_2^+$)
  c   (for DCE only $\pi^-$-$\pi$, $\pi^-$-$\rho$ and $\pi^-$-$a_2$ survive)
  c
MONPAR(7)=1 ! key for SCE generation
  c
MONPAR(8)=0 ! key for DCE generation
  c

c----------------------------------------------- PYTHIA control keys

c
  cMSEL =0 ! full user control
  cMSUB(11)=1 ! $f + f' \rightarrow f + f'$ (QCD)
  cMSUB(12)=1 ! $f + fbar \rightarrow f' + fbar'$
  cMSUB(13)=1 ! $f + fbar \rightarrow g + g$
  cMSUB(28)=1 ! $f + g \rightarrow f + g$
  cMSUB(53)=1 ! $g + g \rightarrow f + fbar$
  cMSUB(68)=1 ! $g + g \rightarrow g + g$
  cMSUB(91)=1 ! Elastic scattering
  cMSUB(92)=1 ! Single diffractive (AX)
  cMSUB(93)=1 ! Single diffractive (XB)
  cMSUB(94)=1 ! Double diffractive
  cMSUB(95)=1 ! Low-pT scattering
  cMSEL =1 ! mb
  MSEL =2 ! mb+sd+dd+elastic+lowpt
  c
MRPY(1)=12031967 ! start point of random number generator
```
Subroutine **MONPARA** reads lines from *moncher.par*. All lines beginning with a letter "c" are ignored by the program, all others lines are processed by subroutine **MONGIVE**, which can recognize any variables from the **MONCHERC**ommon block */MONGPGL/* and the **PYTHIAC**ommon blocks */PYJETS/, */PYDAT1/, */PYDAT2/, */PYDAT3/, */PYDAT4/, */PYDATR/, */PYSUBS/, */PYPARS/, */PYINT1/, */PYINT2/, */PYINT3/, */PYINT4/, */PYINT5/, */PYINT6/, */PYINT7/, */PYINT8/, */PYMSSM/, */PYMSRV/, */PYTCSM/, */PYPUED/, (see [15]). Parameters **MONPARA** are described in detail in the section 3, page 18.

Using parameters from the common blocks listed above, one can define wide spectrum of SCE (**MONPAR(7)=1**) and DCE (**MONPAR(8)=1**) processes or any processes existing in **PYTHIA** (if (**MONPAR(7)=0** and **MONPAR(8)=0**). Some examples are described in the next chapter.

### 7 Examples of the Moncher Processes.

| N | Process | Type of $\pi^+p$ interactions | Picture of the process | The Moncher parameters |
|---|---------|--------------------------------|------------------------|------------------------|
| 1 | $pp \to nX$ | minimum bias: $\pi^+p \to X$ | ![Diagram](image1) | **MONPAR(7)=1**<br>**MONPAR(8)=0**<br>**MSEL=1** |
| 2 | $pp \to n\pi^+p$ | elastic scattering: $\pi^+p \to \pi^+p$ | ![Diagram](image2) | **MONPAR(7)=1**<br>**MONPAR(8)=0**<br>**MSEL=0**<br>**MSUB(91)=1** |
| 3 | $pp \to nXY$ | double diffraction: $\pi^+p \to X+Y$ | ![Diagram](image3) | **MONPAR(7)=1**<br>**MONPAR(8)=0**<br>**MSEL=0**<br>**MSUB(94)=1** |
| 4 | $pp \to nXp$ | single diffraction ($\pi^+$ dissociation): $\pi^+p \to X+p$ | ![Diagram](image4) | **MONPAR(7)=1**<br>**MONPAR(8)=0**<br>**MSEL=0**<br>**MSUB(92)=1** |
| 5 | $pp \to nX\pi^+$ | single diffraction ($p$ dissociation): $\pi^+p \to X+\pi^+$ | ![Diagram](image5) | **MONPAR(7)=1**<br>**MONPAR(8)=0**<br>**MSEL=0**<br>**MSUB(93)=1** |

Table 4: Some S$\pi$E processes which can be generated with **MONCHER**.

It was mentioned already in Chapter 3 that the **MONCHER** generates $p\overline{p}Rn$ vertices and, then, $R\overline{p}$ (for S$\overline{IRE}$) or $R\overline{R}$ (for D$\overline{IRE}$) interactions are generated by **PYTHIA**. The type of these interactions can be controlled by the **PYTHIA** parameters. We can define elastic or inelastic interactions, diffractive or non-diffractive processes, different types of
diffraction, hard scattering, etc. Some of the basic processes for SπE and DπE, which can be generated by the MONCHER, are presented in the tables \([4]\) and \([5]\) respectively.

Let us consider one more simple example, how to generate process number 2 from Table 4. This is a Single Pion Exchange with elastic scattering of the virtual pion by the proton of the beam. This reaction, \(pp \rightarrow n\pi^+p\), has very clear signature: neutron, proton, single \(\pi^+\) meson and nothing else in the final state. Initial particles are scattered at very small angles and, thereof, there are no any detector signals in the region of pseudorapidity \(|\eta| < 7\). An experimental possibility of such measurements has been analysed in Ref. \([8]\) with prereleased version of MONCHER.

File moncher.par with parameters for the generation of \(pp \rightarrow n\pi^+p\) can look as follows:

\[
\begin{align*}
\text{MONPAR}(1) &= 1 \quad \text{! number of events to generate} \\
\text{MONPAR}(2) &= 0 \quad \text{! key for Les Houches data(1-save,0-no)} \\
\text{MONPAR}(3) &= 7000 \quad \text{! pp centre mass energy in GeV (900 -> 14000)} \\
\text{MONPAR}(4) &= 1 \quad \text{! code of model for pR and RR interaction} \\
\text{MONPAR}(5) &= 1 \quad \text{! code of model for absorption} \\
\text{MONPAR}(6) &= 1 \quad \text{! type of Reggeon (1-pi+, 2-rho+, 3-a2+)} \\
\text{MONPAR}(7) &= 1 \quad \text{! key for SCE generation} \\
\text{MONPAR}(8) &= 0 \quad \text{! key for DCE generation} \\
\text{MSEL} &= 0 \quad \text{! full user control} \\
\text{MSUB}(91) &= 1 \quad \text{! elastic scattering}
\end{align*}
\]

Parameter \(\text{MONPAR}(7) = 1\) defines the generation of the SīRE process. Exchange reggeon is a pion \((\text{MONPAR}(6) = 1)\). Pythia parameters \(\text{MSEL}=0\) and \(\text{MSUB}(91)=1\) set elastic \(\pi^+p\) scattering. Parameter \(\text{MONPAR}(4)=1\) sets Donnachie-Landshoff parametrization for \(\pi^+p\) interaction, see subsection \([2.1.2]\). Parameter \(\text{MONPAR}(5)=1\) specifies 3 Pomeron model for absorptive corrections, see subsection \([2.1.1]\). Parameters \(\text{MONPAR}(1)=1\) and \(\text{MONPAR}(3)=7000\) set the generation of 1 event at 7 TeV \(pp\) c.m.s. energy. We don’t ask to save any events \((\text{MONPAR}(2)=0)\) and the only result of the generation is the Pythia listing of the generated event:

\[
\begin{align*}
\text{Event listing (summary)} \\
\text{I} & \quad \text{particle/jet} & \text{KS} & \text{KF} & \text{orig} & \text{p-x} & \text{p-y} & \text{p-z} & \text{E} & \text{m} \\
1 & p+ & 21 & 2212 & 0 & 0.000 & 0.000 & 3500.000 & 3500.000 & 0.938 \\
2 & p+ & 21 & 2212 & 0 & 0.000 & 0.000 & -3500.000 & 3500.000 & 0.938 \\
3 & n0 & 1 & 2112 & 2 & 0.114 & 0.216 & -2296.804 & 2296.804 & 0.940 \\
4 & \pi^+ & 21 & 211 & 2 & -0.114 & -0.216 & -1203.196 & 1203.196 & 0.140 \\
5 & p+ & 21 & 2212 & 3 & -0.019 & -0.001 & 3500.000 & 3500.000 & 0.938 \\
6 & \pi^+ & 21 & 211 & 4 & -0.095 & -0.215 & -1203.196 & 1203.196 & 0.140 \\
7 & p & 1 & 2212 & 5 & -0.019 & -0.001 & 3500.000 & 3500.000 & 0.938 \\
8 & \pi^+ & 1 & 211 & 6 & -0.095 & -0.215 & -1203.196 & 1203.196 & 0.140 \\
\text{sum:} & & & & 2.00 & 0.000 & 0.000 & 0.000 & 7000.000 & 7000.000
\end{align*}
\]

In this listing lines 1 and 2 correspond to the protons of the beams. Lines 3, 7 and 8 relate to the neutron, proton and pion, respectively, in the final state of the reaction. The proton is deflected at angle \(\approx 5.5 \times 10^{-6}\) rad., neutron and pion are scattered in the direction opposite to proton, as it is shown on the diagram of the process in the table \([4]\) with polar angles \(\approx 10^{-4}\) and \(\approx 2 \times 10^{-4}\) rad.
| N | Process | Type of $\pi^+\pi^+$ interactions | Picture of the process | The Moncher parameters |
|---|---------|---------------------------------|------------------------|-----------------------|
| 1 | $pp \rightarrow nXn$ | minimum bias: $\pi^+\pi^+ \rightarrow X$ | ![minimum bias](image) | MONPAR(7)=0 MONPAR(8)=1 MSEL=1 |
| 2 | $pp \rightarrow n\pi^+\pi^+n$ | elastic scattering: $\pi^+\pi^+ \rightarrow \pi^+\pi^+$ | ![elastic scattering](image) | MONPAR(7)=0 MONPAR(8)=1 MSEL=0 MSUB(91)=1 |
| 3 | $pp \rightarrow nXYn$ | double diffraction: $\pi^+\pi^+ \rightarrow X + Y$ | ![double diffraction](image) | MONPAR(7)=0 MONPAR(8)=1 MSEL=0 MSUB(94)=1 |
| 4 | $pp \rightarrow nX\pi^+n$ | single diffraction: $\pi^+\pi^+ \rightarrow X + \pi^+$ | ![single diffraction](image) | MONPAR(7)=0 MONPAR(8)=1 MSEL=0 MSUB(92)=1 or MSUB(93)=1 |

Table 5: Some DπE processes which can be generated with Moncher.

**Acknowledgements**

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