Pomeron-pomeron cross section from inclusive production of a central cluster in quasi-elastic $\pi^+p$ and $K^+p$ scattering at 250 GeV/c

EHS/NA22 Collaboration


1 Department of Physics, Universitaire Instelling Antwerpen, B-2610 Wilrijk and Inter-University Institute for High Energies, B-1050 Brussels, Belgium
2 Institute of Physics and Nuclear Technique of Academy of Mining and Metallurgy and Institute of Nuclear Physics, PL-30055 Krakow, Poland
3 Nuclear Physics Institute, Moscow State University, 119899 Moscow, Russia
4 University of Nijmegen and NIKHEF-H, NL-6526 ED Nijmegen, The Netherlands
5 Centro Brasileiro de Pesquisas Físicas, 22290 Rio de Janeiro, Brazil
6 Institute of High Energy Physics of Tbilisi State University, 380086 Tbilisi, Georgia
7 Institute of Physics, 375036 Yerevan, Armenia

Received 14 May 1993

Abstract. Meson-nucleon quasi-elastic scattering is studied with (semi) inclusive production of a central hadron cluster. The dominant mechanism of central cluster production is double pomeron exchange. The cross section is $(39 \pm 5 \pm 8)$ mb and $(24 \pm 6 \pm 3)$ mb for pion and kaon induced reactions, respectively. An estimate of the pomeron-pomeron total cross section $\sigma_{pp}$ is extracted in the interval $4m_{\pi} < \sqrt{s_{pp}} < 2$ GeV. While $\sigma_{pp} = 0.45 \pm 0.01$ mb is obtained in the $f_2(1270)$ region, an almost constant cross section with an average of $\sigma_{pp} \approx 0.16 \pm 0.02$ mb is observed outside the $f_2$ region.

1 Introduction

Diffractive processes, observed both in hadron-hadron and lepton-hadron scattering, proceed predominantly via pomeron exchange. Despite extensive studies of diffractive elastic scattering and inelastic diffraction dissociation in hadron-nucleon interactions, the nature of the pomeron is still not well understood. More light can be shed on its properties by an investigation of processes proceeding via pomeron-pomeron interactions. The simplest one among these is the process of double pomeron exchange (DPE) playing a dominant role in quasi-elastic hadron-hadron scattering with a diffractively produced central hadron cluster. Exclusive processes of pomeron-pomeron interactions have been studied in proton-proton collisions at ISR energies (see Refs. in [1] and [2-4]), as well as in proton-proton and meson-proton collisions at SPS fixed target energies (see [5-7] and Refs. therein). So far, (semi) inclusive pomeron-pomeron interactions have been studied in quasi-elastic $pp$-scattering at $\sqrt{s} = 62$ GeV [8] and 630 GeV [9].

In this work, an attempt is made to extract new information on the low energy pomeron-pomeron interaction from quasi-elastic $\pi^+p$ and $K^+p$ scattering at 250 GeV/c,

$$\pi^+p \rightarrow \pi^+\pi^- p + X_n, \quad (1)$$

$$K^+p \rightarrow K^+\pi^- p + X_n, \quad (2)$$

where $X_n$ indicates a centrally produced hadron cluster with charge multiplicity $n = 0, 2$ or 4.

2 Experimental procedure

The experiment has been performed at CERN in the European Hybrid Spectrometer (EHS) equipped with the $\mathrm{H}_2$ filled Rapid Cycling Bubble Chamber (RCBC) as a vertex detector. The experimental set-up and the trigger conditions are described in detail in [10-12]. Tracks of secondary charged particles are reconstructed from hits in the wire and drift chambers of the two-lever-arm spec-
trometer and from measurements in RCBC. The momentum resolution varies from (1–2)% for tracks reconstructed in the bubble chamber to (2–2.5)% for tracks reconstructed in the first lever arm and to 1.5% for tracks reconstructed in the full spectrometer.

Our results are based on 144169 events of $\pi^+p$ and 49565 events of $K^+p$-interactions. Events selected as candidates for quasi-elastic scattering have an arbitrary topology, but contain two properly reconstructed leading hadrons: a fast positive hadron with Feynman $x_M > 0.9$ (assumed to be a $\pi^+$ for reaction (1) and a $K^+$ for reaction (2)) and an identified proton with $x_p < -0.9$. The identification of protons with lab. momentum $p_1 > 1.2$ GeV/c is obtained from a special visual ionization scan for the full $K^+p$ sample and for 62% of the $\pi^+p$ sample. For the remaining $\pi^+p$ sub-sample, the efficiency for proton identification (obtained from an “automatic” identification procedure) is noticeably less than unity and decreases with increasing squared four-momentum transfer $|t_{\pi^+p}|$ to the proton. In order to compensate the losses due to proton misidentification, $|t_{\pi^+p}|$-dependent weights are introduced for this sub-sample (see Table 1).

Events with low squared four-momentum transfer to the quasi-elastically scattered meson ($|t_{\pi^+M}| < 0.03$ GeV$^2$) have very low trigger efficiency and are excluded. The remaining events are weighted to correct for losses induced by the interaction trigger [13]. Losses due to bad reconstruction of the leading particle tracks are taken into account in the normalized cross section $\sigma_1 = 0.37 \mu b$ for the $\pi^+p$ sample with ionization scan and $\sigma_0 = 0.50 \mu b$ for the $K^+p$ sample.

Due to the limited experimental resolution, the separation of central cluster production at very low mass $m_X$ of the central cluster is complicated by the contamination from elastic scattering [13] and single $\pi^0$ production. In the mass region $m_X \leq 4m_\pi$, the only DPE channels are the two pion production channels

$$\pi^+p \rightarrow \pi^+_f p + (\pi^+\pi^-), \quad (3)$$
$$K^+p \rightarrow K^+_f p + (\pi^+\pi^-), \quad (4)$$
$$\pi^+p \rightarrow \pi^+_f p + (\pi^0\pi^0), \quad (5)$$
$$K^+p \rightarrow K^+_f p + (\pi^0\pi^0). \quad (6)$$

Channels (3) and (4) have been studied at low $m_X$ in our previous analysis [7]. Because of the iso-singlet nature of the pomeron, the cross section of (5) and (6) is half of that of (3) and (4). So, the DPE contribution to channels (5) and (6) can be determined from that to channels (3) and (4), respectively.

Taking into account the above, we restrict the study of inclusive reactions (1) and (2) to the mass region $m_X > 4m_\pi$, which leads to the following restrictions on the four-momentum of the leading proton $p_p$ and of the leading meson $p_M$:

$$m^2_{M,X} = (p_1 + p_2 - p_p)^2 > (m_M + 4m_\pi)^2,$$
$$m^2_{M,X} = (p_1 + p_2 - p_M)^2 > (m_M + 4m_\pi)^2,$$
$$m^2_{M,X} = (p_1 + p_2 - p_p - p_M)^2 > 16m^2_\pi,$$
where $p_1$ and $p_2$ are the four-momenta of the incident hadrons. Note, that $m^2_{M,X}$ is restricted from above by condition $|x_{lead}| > 0.9$ corresponding to $m^2_{M,X} < 0.01 s \approx 4.7$ GeV$^2$.

3 The cross sections

The histogram in Fig. 1 shows the distribution in the azimuthal angle $\phi$ of the leading hadron in the Gottfried-Jackson frame*. It is strongly peaked at $\phi \approx 180^\circ$. The largest part of events with $\phi = 175^\circ-180^\circ$ are two-prong events (represented by the non-shaded area under the histogram) and correspond to a residual from elastic scattering, for which the azimuthal angle has to be $\phi = 180^\circ$ (or slightly less due to the measuring error). After excluding the shaded area, the distribution still slightly differs from the isotropic one expected for DPE. This indicates a possible contamination by single pomeron exchange (SPE) processes. Figure 1 also gives the data for four-prong exclusive channels (3) and (4) shown to be produced predominantly via DPE in [7].

The number of events from the (semi)inclusive reactions (1) and (2) (at $|x_{lead}| > 0.9$, $m_X > 4m_\pi$ and $|t_{\pi^+M}| > 0.03$ GeV$^2$) are given in Table 2 for different topologies, together with the corresponding cross section.

The correction for the loss at $|t_{\pi^+M}| < 0.03$ GeV$^2$ is estimated from a fit to the experimentally observed spectra $d\sigma/dt_{\pi^+M}$ by the exponential form $\sim \exp[\beta(t + 0.03)]$. The slope parameters $b_a$ and $b_M$, as well as the slope $b_y$ of the spectrum $d\sigma/dt_{\pi^+M}$ are presented in Table 3. Except for $b_y$ in the 2-prong reaction, the slopes of $\pi^+$-induced reactions significantly exceed those of $K^+$-induced reactions. In all types of reactions the proton slope $b_p$ is larger than the meson slope $b_M$. Also the correspondingly corrected cross sections are given in Table 2.

The cross sections of the inclusive meson-proton quasi-elastic scattering are:

$$\sigma(\pi^+p \rightarrow \pi^+_f p X) = 55 \pm 7 \mu b \quad |x_{lead}| > 0.9$$

$$\sigma(K^+p \rightarrow K^+_f p X) = 35 \pm 5 \mu b \quad m_X > 4m_\pi.$$

* This is defined as the rest frame of the system ($X_0$ leading hadron), with the corresponding incident hadron defining the positive $z$-axis and the $xz$-plane composed by the incident hadron and the second leading hadron, having positive momentum projection along the $x$-axis [14].
Table 2. The number of (weighted) events and the cross section of reactions (1) and (2) at |t_{rel}| > 0.9 and m_x > 4 m_x

| Reaction | Topology | N | ΣW | σ (μb) \left| t_{M-M'} \right| > 0.03 GeV^2 | σ (μb) corrected | N | ΣW | σ (μb) \left| t_{M-M'} \right| > 0.03 GeV^2 | σ (μb) corrected |
|----------|----------|---|-----|--------------------------------|------------------|---|-----|--------------------------------|------------------|
| π⁺ p     | 2 prong  | 23 | 41.2| 13.1 ± 2.8                           | 16.1 ± 3.5       | 13 | 19.9| 10.0 ± 2.7                           | 11.6 ± 3.2       |
|          | 4 prong  | 56 | 116.5| 31.0 ± 4.7                           | 36.4 ± 5.5       | 24 | 37.4| 18.0 ± 3.8                           | 21.0 ± 4.3       |
|          | 6 prong  | 4  | 5.5 | 19.0 ± 0.9                            | 23 ± 1.2         | 3  | 0.0 | 2.0 ± 0.1                            | 2.3 ± 1.3        |
| Total    |          | 83 | 163.0| 46.0 ± 4.9                            | 54.8 ± 6.6       | 40 | 61.3| 30.0 ± 4.8                            | 34.9 ± 5.5       |

Table 3. The slope parameters of the spectra dσ/dt in reactions (1), (2)

<table>
<thead>
<tr>
<th>Reaction</th>
<th>b(π⁺) (GeV/c)^{-2}</th>
<th>b(K⁺) (GeV/c)^{-2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 prong</td>
<td>6.9 ± 0.8</td>
<td>4.6 ± 0.8</td>
</tr>
<tr>
<td>4 prong</td>
<td>5.0 ± 0.2</td>
<td>3.8 ± 0.4</td>
</tr>
<tr>
<td>total</td>
<td>5.2 ± 0.2</td>
<td>4.0 ± 0.3</td>
</tr>
</tbody>
</table>

These values can be compared with the corresponding cross section (for 4m_x < m_p < 2 GeV/c^2) in pp-interactions at √s = 62 GeV [8]: σ(pp→ppX)≈130 ± 20 μb (the quoted error does not include a systematic error resulting from an overall uncertainty on the acceptance and the luminosity calibration, estimated to be a factor of 1.5).

If DPE dominates in the proton, pion and kaon induced reactions, the ratio of the corresponding cross sections is expected to be 1:0.47:0.43 (see, e.g., the (15) in [7]). Taking into account the statistical and systematic errors, the measured ratio 1:(0.42 ± 0.05): (0.27 ± 0.04) does not contradict the theoretical expectation. As seen from Table 2, two charged particles are produced in the central region in 60% of the reactions. This corresponds to a cross section

σ(π⁺ p → π⁺ p + π⁻ + π⁻) = 36 ± 5 μb, \hspace{1cm} (8)

These values can be compared with the cross sections

σ(π⁺ p → π⁺ p + π⁻ + π⁻) = 28 ± 4 μb, \hspace{1cm} (9)

and with the DPE cross sections

σ_{DPE}(π⁺ p → π⁺ p + π⁻ + π⁻) = 21 ± 4 μb, \hspace{1cm} (10)

σ_{DPE}(K⁺ p → K⁺ p + π⁺ + π⁻) = 14 ± 4 μb

of the exclusive channels (3) and (4) subject to the same kinematical restrictions (see [7]).

A comparison of (8) and (9) shows that central production of more than two pions or of a charged kaon pair with effective mass m_x < 2 GeV/c^2 occurs in the channels contributing to (8) with a cross section much smaller than that for a charged pion pair given in (9):

σ(π⁺ p → π⁺ p) + (π⁺ π⁻ π⁺ π⁻, K⁺ K⁻, etc.) = 8 ± 7 μb, \hspace{1cm} (11)

It follows from (9) and (10) that about 70% of the exclusive reactions (3) and (4) proceed via DPE. As men-
tioned in the Sect. 2, the DPE cross section of the two-prong exclusive channels (5) and (6) are expected to be half of the cross section (10):

$$\sigma_{\text{DPE}}(\pi^+ p \rightarrow \pi_f^+ p + \pi^0 \pi^0) = 10 \pm 2 \mu b,$$

$$\sigma_{\text{DPE}}(K^+ p \rightarrow K_f^+ p + \pi^0 \pi^0) = 7 \pm 2 \mu b.$$  

(12)

Therefore, using (12) and data of the first line of Table 2, the cross section for central production of more than two neutral pions or a neutral kaon pair is:

$$\sigma(\pi^+ p \rightarrow \pi_f^+ p + 3 \pi^0, 4 \pi^0, K^0 \bar{K}^0) < 10 \mu b,$$

$$\sigma(K^+ p \rightarrow K_f^+ p + 3 \pi^0, 4 \pi^0, K^0 \bar{K}^0) < 8 \mu b,$$

(13)

at 68% confidence level.

The lower limit of the DPE cross section in the inclusive reactions (1) and (2) can be estimated as the sum of cross sections (10) and (12):

$$\sigma_{\text{DPE}}(\pi^+ p \rightarrow \pi_f^+ p X) > \sigma_{\text{DPE}}(\pi^+ p \rightarrow \pi_f^+ p + 2 \pi) = 31 \pm 5 \mu b,$$

$$\sigma_{\text{DPE}}(K^+ p \rightarrow K_f^+ p X) > \sigma_{\text{DPE}}(K^+ p \rightarrow K_f^+ p + 2 \pi) = 21 \pm 6 \mu b,$$

which compose 55–60% of the measured inclusive cross sections (7).

An upper limit of the DPE cross section can be obtained by subtracting from (7) the difference of the cross sections (9) and (10), i.e. the cross section corresponding to the SPE events in the 4-prong exclusive channel (see [7]):

$$\sigma_{\text{DPE}}(\pi^+ p \rightarrow \pi_f^+ p X) < 48 \pm 7 \mu b,$$

$$\sigma_{\text{DPE}}(K^+ p \rightarrow K_f^+ p X) < 26 \pm 6 \mu b.$$  

(15)

Another estimate of the upper limit of the DPE cross section can be obtained from the rapidity gap method [15–17]. According to this, in the DPE reaction the rapidity gap A between the leading hadron and the neighbouring centrally produced hadron should exceed two units. Excluding 4- and 6-prong events with A < 2, we obtain for the remaining (the “DPE enriched”) subsample (68 π+ p and 30 K+ p events):

$$\sigma_{\text{DPE}}(\pi^+ p \rightarrow \pi_f^+ p X) < 47 \pm 6 \mu b,$$

$$\sigma_{\text{DPE}}(K^+ p \rightarrow K_f^+ p X) < 27 \pm 5 \mu b,$$

(16)

in agreement with (15). The dominant contribution to (16) comes from the two-pion cross sections (14): ~65% and ~80% for the pion and kaon induced reactions, respectively. As some contribution into the “DPE enriched” sample can come from the other DPE processes (leading to the production of four pions or a K K pair), one can conclude that the SPE background in the “DPE enriched” sample is negligible for the kaon induced reaction and very small for the pion induced reaction.

Combining (14) and (16) we obtain an estimate for the DPE cross section in the inclusive channel:

$$\sigma_{\text{DPE}}(\pi^+ p \rightarrow \pi_f^+ p X) = 39 \pm 5 \pm 8 \mu b,$$

$$\sigma_{\text{DPE}}(K^+ p \rightarrow K_f^+ p X) = 24 \pm 6 \pm 3 \mu b,$$

(17)

where the first quoted error is statistical and the second one reflects a possible dispersion between the lower (14) and upper (16) limits. The ratio of the DPE cross sections of 0.62 ± 0.17 ± 0.15 is, within error, in agreement with the theoretical expectation of 0.91 (see above).

Note also, that after excluding events with A < 2, the estimate for the DPE cross section for 6-prong events is:

$$\sigma_{\text{DPE}}(\pi^+ p \rightarrow \pi_f^+ p + X_6) = 2 \pm 1 \mu b,$$

$$\sigma_{\text{DPE}}(K^+ p \rightarrow K_f^+ p + X_6) = 2 \pm 1 \mu b.$$  

(18)

4 The characteristics of reactions (1) and (2) and the pomeron-pomeron total cross section

A number of characteristics of the inclusive reactions (1) and (2) are presented in Figs. 2–4 and Table 4. Figure 2 shows the rapidity y distribution for the leading hadrons and the central cluster. As expected for DPE reactions, the latter is peaked near y = 0.

The distribution in the effective mass m_{hX} of the leading hadron h and the central cluster X(\pi^+ and K^+ induced reactions combined) is shown in Fig. 3. Near threshold this distribution has a rise due to phase space, but as expected for DPE it flattens at the highest available mass.

The distribution in the effective mass m_{hX} of the central cluster (Fig. 4a) has an indication for a local maximum near the mass of the f_2(1270) (J = 0, J^PC = 2 + +) allowed to be produced in pomeron-pomeron interaction. Figure 4b shows the central cluster mass distribution for the “DPE enriched” sample (with A > 2).

From comparison of Fig. 4b with the theoretical expression for the differential cross section d\sigma_{\text{DPE}}/dM_{hX}, weighted appropriately for \pi^+ and K^+ induced reactions (see (15) in [7]), we extract the massless pomeron-pomeron total cross section \sigma_{pp}^{tot}(\sqrt{s_{pp}}) shown in Fig. 5. In the same figure data are shown at lower energy, \sqrt{s_{pp}} < 0.75 GeV from [7] and \sqrt{s_{pp}} ~ 3.6 GeV extracted in [7] from the data on the reaction pp \rightarrow ppX [18]. The pomeron-pomeron total cross section rises near the two-pion threshold and becomes constant within errors at m_{hX} < \sqrt{s_{pp}} < 2 GeV, except for the f_2(1270) region where it is noticeably peaked with \sigma_{pp}^{tot} \approx 0.45 \pm 0.10 mb. Outside the f_2(1270) region, the averaged cross section is \sigma_{pp} = 0.16 \pm 0.02 mb.

Note, that the combined “DPE enriched” sample can contain at most (15 ± 15)% contamination from the SPE processes (see Sect. 3 above). The extracted cross section can, therefore, be slightly overestimated, but not more than the quoted error. The quoted pomeron-pomeron total cross section is by almost two orders smaller than the hadron-hadron cross section, implying a very small geometrical size of the pomeron [19].
Fig. 2. The rapidity distribution for the leading hadrons and the central cluster in reactions (1) and (2)

Fig. 3. The distribution in the effective mass of the leading hadron and the central cluster in reactions (1) and (2) combined

Fig. 4a, b. The central cluster mass distribution for reactions (1) and (2) combined; a for the whole sample, b for the "DPE enriched" subsample

Table 4. Average characteristics of reactions (1) and (2)

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$\langle x_p \rangle$</th>
<th>$\langle x_M \rangle$</th>
<th>$\langle y_p \rangle$</th>
<th>$\langle y_M \rangle$</th>
<th>$\langle m_{x+p} \rangle$ (GeV/c²)</th>
<th>$\langle m_{x+M} \rangle$ (GeV/c²)</th>
<th>$\langle m_x \rangle$ (GeV/c²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+p$</td>
<td>$-0.945 \pm 0.003$</td>
<td>$0.939 \pm 0.003$</td>
<td>$-3.04 \pm 0.01$</td>
<td>$3.96 \pm 0.05$</td>
<td>$5.27 \pm 0.13$</td>
<td>$4.91 \pm 0.16$</td>
<td>$1.03 \pm 0.04$</td>
</tr>
<tr>
<td>$K^+p$</td>
<td>$-0.942 \pm 0.004$</td>
<td>$0.939 \pm 0.003$</td>
<td>$-3.01 \pm 0.02$</td>
<td>$3.41 \pm 0.04$</td>
<td>$5.26 \pm 0.16$</td>
<td>$5.17 \pm 0.19$</td>
<td>$1.11 \pm 0.06$</td>
</tr>
</tbody>
</table>
5 Summary

The meson-nucleon quasi-elastic scattering with (semi) inclusive production of a central hadron cluster is studied at an incident momentum of 250 GeV/c. The inclusive cross section of $\pi^+$ and $K^+$ meson induced production of a central cluster with mass $4m_{\pi} < m_X < 2$ GeV/c$^2$ is measured to be

$$\sigma(\pi^+ p \rightarrow \pi^+_f pX) = 55 \pm 7 \text{ mb},$$

$$\sigma(K^+ p \rightarrow K^+_f pX) = 35 \pm 5 \text{ mb}.$$  

It is shown that the dominant mechanism in these reactions is the DPE process with an estimated cross section of

$$\sigma_{DPE}(\pi^+ p \rightarrow \pi^+_f pX) = 39 \pm 5 \pm 8 \text{ mb},$$

$$\sigma_{DPE}(K^+ p \rightarrow K^+_f pX) = 24 \pm 6 \pm 3 \text{ mb}.$$  

An indication for central production of the $f_2(1270)$ meson is observed. The massless pomeron-pomeron total cross section $\sigma_{pP}$ is estimated in the interval $4m_{\pi} < s_{pP} < 2$ GeV. In the $f_2(1270)$ region $\sigma_{pP} \approx 0.45 \pm 0.10 \text{ mb}$ is obtained, while outside this region the pomeron-pomeron total cross section is almost independent of energy with an averaged value of $\sigma_{pP} = 0.16 \pm 0.02 \text{ mb}$.

Acknowledgements. It is a pleasure to thank the EHS coordinator L. Montanet and the operating crews and staffs of EHS, SPS and H2 beam, as well as the scanning and processing teams of our laboratories for their invaluable help with this experiment. We are grateful to III. Physikalisches Institut B, RWTH Aachen, Germany, DESY-Institut für Hochenergiephysik, Berlin-Zeuthen, Germany, Department of High Energy Physics, Helsinki University, Finland, University of Warsaw and Institute of Nuclear Problems, Warsaw, Poland for early contributions to this experiment. We thank the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) for support of this project within the program for subsistence to the former Soviet Union (07-13-038).

References