acta phys. slov. 28. (1978), No. 4

MULTIPARTICLE PRODUCTION IN $\pi^{\pm}p$ INTERACTIONS AT 150 GeV/c AND THE QUARK PARTON MODEL

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We study the multiparticle production in pion-proton collisions at 150 GeV/c from the point of view of the quark-parton model. Currently available data are compared with the predictions following from the recent model by V. Černý, P. Lichard and J. Pišút. The results are found to be in a good qualitative agreement with the general features of the data. A particulary promising qualitative agreement is obtained in the delicate problem of charge distribution in the final state.

МНОГОЧАСТИЧНАЯ ПРОДУКЦИЯ В $\pi^{\pm}p$ ВЗАИМОДЕЙСТВИЯХ ПРИ 150 Гэв/с И КВАРК-ПАРТОННАЯ МОДЕЛЬ

В статье изучается многочастичная продукция в пион-протонных столкновениях при 150 Гэв/с с точки зрения кваркпартонной модели. Проводится сравнение последних опубликованных данных с предсказаниями из модели, недавно предложенной В. Черны, П. Лихардом и Я. Пишутом. Показано, что результаты находятся в хорошем качественном согласии с общим характером данных. Частично обнадёживающее качественное согласие получено также в интересной проблеме зарядового распределения в конечном состоянии.

I. INTRODUCTION

The multiparticle production in hadronic collisions is receiving today a considerable attention both from the experimental and the theoretical side. In fact, the multiparticle production brings information which is, in a sense, complementary to that provided by the data on deep inelastic lepton-nucleon scattering.

Theoretical studies of multiparticle production are rather difficult, because the theory of strong interactions is still non-existing. In this situation abundant data are most frequently obtained by using phenomenological models. At present the most popular is the quark-parton model which has a unique chance to explain the basic features of both the deep inelastic lepton nucleon scattering and the multiparticle production from a single point of view.

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In a recent paper [1, 2] V. Černý, P. Lichard and J. Pišút have constructed a Monte Carlo quark-parton model of multiparticle production. The advantages of the Monte Carlo method are obvious — the predictions of the model can be compared with any kind of data (provided that the program does not consume too much computer time).

n the original papers [1, 2] the authors have applied the model to multiple production in proton-proton collision at laboratory energies above 100 GeV/c.

In the present paper we shall apply the same model to $\pi^{\pm}p$ collisions at 150 GeV/c and compare the results obtained with the currently available data.

The model, as it stands now, makes no attempt to describe quantitatively all features of the data. It seems wiser to look at present only at the qualitative properties of the data. In doing so one can hope to recognize the weaker and the stronger points of the model.

Then, it may turn out, that weaker points will require the same or similar modification of the model. After having performed such corrections one can start with making more detailed and quantitative studies of various processes.

For the moment, however, the general policy[1]) is to keep the model fixed and compare it with as many data as possible.

In this sense the present paper, as well as the recent study [3] of multiple production in $\bar{p}p$ collisions represents a search for possible qualitive disagreements of the model by V. Černý, P. Lichard, and J. Pišút [1, 2] with the data.

The paper is organized as follows. In the next section we describe for the sake of completness the basic features of the Monte Carlo quark-parton model of multiple production [1, 2]. Our discussion is not intended to be quite complete and for details the reader is referred to the original publications. What we discuss in some detail are only the differences between the model as applied to *pp* and to πp collisions.

Next, in Section III we compare the results obtained with the data from πp interactions 150 GeV/c. The last section contains a few comments and conclusions.

II. THE QUARK-PARTON MODEL OF MULTIPARTICLE PRODUCTION IN HADRONIC COLLISIONS

The model [1, 2] is based on the assumption [4, 5] that hadrons are coherent superpositions of valence quarks, "sea" quarks and gluons. The hadronic collision is initiated by the interaction of wee partons. After that a compound system is

1) The author is indebted to V. Černý, P. Lichard and J. Pišút for valuable discussions about this matters.

formed. It is further assumed that during the collision gluons are converted to $\bar{Q}Q$ pairs and mesons, baryons and antibaryons are formed by recombination of $\bar{Q}Q$ pairs, QQQ and $\bar{Q}\bar{Q}\bar{Q}$ triplets.

The recombination process is of a short range in rapidity so that only those partons[2)] which are separated by small rapidity gaps can recombine. In the model one does not try to describe the whole evolution of the collisions but starts with generating the distribution of partons in a cylindrical phase space.

In the present paper we shall study the pion-proton collisions, where we have 5 valence partons in the compound system (a Q and an $\bar{Q}$ for the pion an QQQ for the proton).

The probability to find a compound system consisting of 5 valence partons with rapidities and transverse momenta $y_1, p_{t_1}, \ldots, y_5, p_{t_5}$ plus n quarks with $y_6, p_{t_6}, \ldots, y_{n+5}, p_{t_{n+5}}$ and n antiquarks with $y_{n+6}, p_{t_{n+6}}, \ldots, y_{2n+5}, p_{t_{2n+5}}$ is given as follows ($N=2n+5$)

$$dP_N(y_1, p_{t_1}, \ldots, y_N, p_{t_N}) = KG^{2n} W_{id} \left(\prod_1^5 |x_i|^{1/2}\right) \qquad (1)$$
$$\exp\left(-\sum_1^N p_{t_i}^2/R^2\right) \delta(E-\Sigma E_i)\, \delta\left(\sum_1^N p_i\right) \prod_1^N \left(\frac{dp_i}{2E_i}\right).$$

Here K is an overall constant, assumed to be independent of the energy of the collision, W_{id} is a factor for identical particles, which is here in the same way as in [1], G is a "coupling constant" regulating the average multiplicity and R represents the cut off on transverse momenta of partons. The rest of Eq. (1) is the standard cylindrical phase space modified by the Kuti-Weisskopf [18] weight factors $|x_i|^{1/2}$ pressing, in fact, valence quarks to higher values of momentum fractions x_i.

The relative amount of the production of strange particles is given by a parameter λ which specifies the probability that a given $\bar{Q}Q$ pair is of the $u\bar{u}$, $d\bar{d}$ or $s\bar{s}$ type. The parameter λ is defined as follows

$$\lambda = \frac{\text{probability of } \bar{s}s}{\text{probability of } \bar{u}u}$$

and it is assumed that the $\bar{u}u$ and $\bar{d}d$ pairs (from the "sea") occur with equal probabilities.

The parameters G, R^2, λ completely specify the program.

We have used here exactly the same values as those used in [1, 2] so that the qualitative features of the model can be well checked. It is to be noted that these parameters should be the same in both cases because of the physics behind the model.

[2)] In what follows a parton means either a quark or an antiquark.

We have used the following values of these parameters: $R^2=0.21$ (GeV/c)^2; $G=1.15$; $\lambda=0.22$.

At first sight it might seem that the suppression of strange $\bar{Q}Q$ pairs is too strong, since in earlier papers [6, 7] higher values of λ were used. This is, however, not quite so because the factor for identical particles W_{id} works in the opposite direction, preferring those particles which have lower average multiplicities. Thus, in fact, the effective suppression of strange quarks is closer to 1/3 than to 1/5.

After having generated the exclusive configuration of partons according to Eq. (1) the program proceeds by recombining the neighbours in rapidity to mesons ($\bar{Q}Q$ pairs), baryons (QQQ triplets) and antibaryons ($\bar{Q}\bar{Q}\bar{Q}$ triplets). The probability of forming a particular meson m_k from a given combination $Q_i\bar{Q}_j$ is proportional to the square of the coefficient C_{ij}^k which stands in the SU(6) wave function of the meson

$$m_k = \sum_{i,j} c_{ij}^k Q_i \bar{Q}_j .$$

In an analogous way one obtains the probability of a recombination of a triplet $Q_iQ_jQ_k$ to a particular baryon B_l. One also averages over spins of the recombining quarks and performs the spin sums of the hadrons being formed. In this model [1, 2] one takes into account only the production of mesons from the 35-plet of the SU (6) group and baryons and antibaryons from the 56 plets.

In the last stage the unstable particles decay to stable hadrons and leptons observed in the final state.

This part of the program is described in detail in the original papers [1, 2] and because of that we shall omit here the discussion of these issues.

III. THE COMPARISON OF THE RESULTS WITH THE DATA ON π^+p COLLISIONS AT 150 GeV/c

Let us start by discussing the average charge multiplicity. At the 150 GeV/c π^-p interaction we obtain $\langle n_c \rangle = 7.46 \pm 0.33$, whereas for π^+p at the same energy we get $\langle n_c \rangle = 8.25 \pm 0.22$. These two points are plotted in Fig. 1 and compared with the data at somewhat lower energies. It can immediately be seen that the general trend of data ([8] Fig. 14) indicates that our values for $\langle n_c \rangle$ at 150 GeV/c are most likely correct.

It is worth stressing that for the "coupling constant" G, which regulates the average multiplicities, the same value was taken as in studies of the proton-proton collisions [1, 2]. This indicates that the multiple production in both πp and pp interactions is governed by the samemechanism and that the model [1, 2] may well reflect correctly some of its general features.

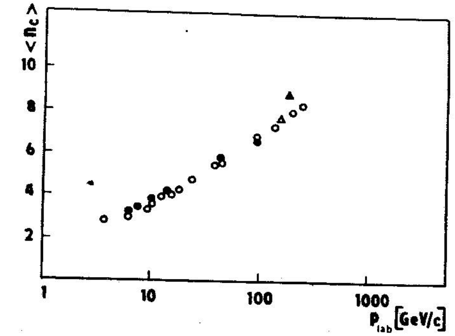

Fig. 1. The average charge particle multiplicities per inelastic $\pi^{\pm}p$ collisions as a function of incident beam momentum. Symbols: experimental values: ○ – π^-p, ● – π^+p; calculated values: △ π^-p, ▲ π^+p. Experimental data are taken from Fig. 8a in [15].

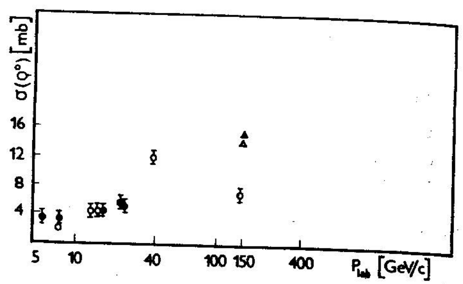

Fig. 2. Inclusive ϱ^0 cross section as a function of the incident beam momentum. The symbols have the same meaning as in Fig. 1. Experimental data are taken from Fig. 56 in [15].

The following Figs. 2, 3, 4 and 5 present the data on the dependence of inclusive cross sections for production of ϱ^0, Λ, $\bar{\Lambda}$ and K_S^0 on the laboratory momentum of the incident pion. Values of particular cross sections calculated by model [1, 2] are given in Tab. 1.

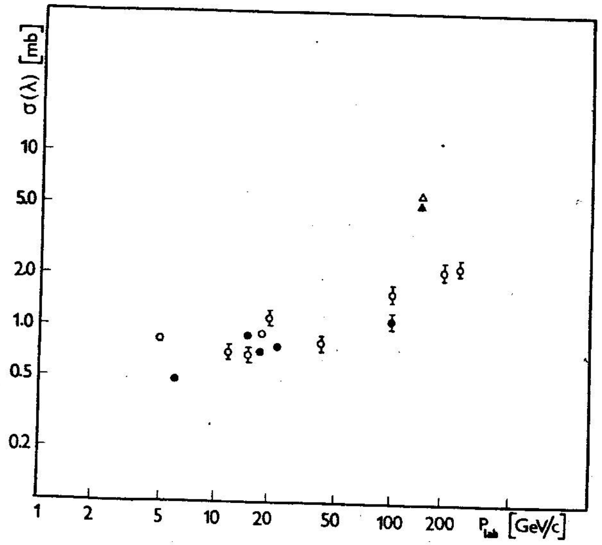

Fig. 3. Inclusive Λ cross section as a function of the incident beam momentum. The symbols have the same meaning as in Fig. 1. Experimental data are taken from Fig. 41 in [15.].

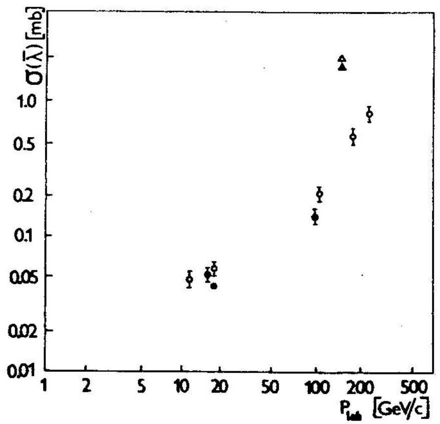

Fig. 4. Inclusive $\bar{\Lambda}$ cross section as a function of the incident beam momentum. The symbols have the same meaning as in Fig. 1. Experimental data are taken from Fig. 42 in [15].

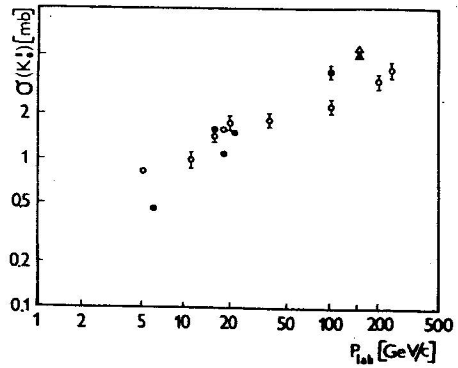

Fig. 5. Inclusive K_S^0 cross section as a function of the incident beam momentum. Symbols have the same meaning as in Fig. 1. Experimental data are taken from Fig. 40 in [15].

Table 1

	π^+p	π^-p
$\sigma(\varrho^0)$	15.17 ± 0.71	15.09 ± 0.67
$\sigma(\Lambda)$	5.44 ± 0.77	5.85 ± 0.96
$\sigma(\bar{\Lambda})$	1.81 ± 0.24	1.96 ± 0.37
$\sigma(K_S^0)$	5.27 ± 0.52	5.38 ± 0.21
$\sigma(\pi^0)$	76.75 ± 2.76	76.85 ± 10.75

The comparison of $\langle n_{\varrho^0} \rangle$ with the data is a rather delicate problem. At present two types of analysis of experimental data are being used. The former is sometimes referred to as the "conventional" one and the latter as the "unconventional" one. The description of the "unconventional" analysis can be found in Ref. [13] for πp collisions and in [14] for pp interactions at high energies. As it is well known, the cross section obtained in the "unconventional" analysis is about three times larger than in the "unconventional" analysis is about three times larger than in the "conventional" one. This is seen also in Fig. 2, where results at 40 GeV/c (Grishin's group at Dubna [13]) is considerably larger than the results at both the lower and the higher energies. As was shown in [2] the results obtained in the present model coincide with those obtained in the "unconventional" analysis and, of course, disagree with the results of the other one. This point is also seen in Fig. 2, where our result is higher by approximately a factor of 3 than the results obtained by the "conventional" analysis.

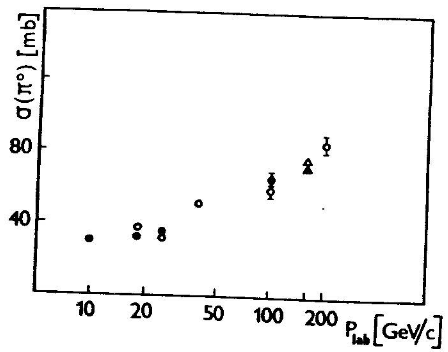

Fig. 6. Inclusive π^0 cross section as a function of the incident beam momentum. Symbols have the same meaning as in Fig. 1. Experimental data are taken from Fig. 38 in [15].

The agreement with the data on K_S^0 production is rather good (Fig. 5), whereas our results for the Λ and $\bar{\Lambda}$ productions disagree with the data. In fact the Λ and $\bar{\Lambda}$ productions are known to be a serious problem for the quark-parton models [1, 2, 6] of multiparticle production. We shall not discuss this problem further here.

In Fig. 6 we compare our result of the inclusive π^0 cross section with the available data. The agreement is very good[3)].

In Fig. 7 we present the dependence of the inclusive production of π^+ and ϱ^0 on the transverse momentum for the π^-p collision at 150 GeV/c. We can see important difference between the $d\sigma/dp_t^2$ at a low p_t for π^* and the ϱ^0 production. This difference is usually being interpreted [12] as resulting from the fact that the ϱ^0 are produced "directly" whereas most of the pions come from decays of resonances. As a result the pion distribution is more peaked at a low p_t.

In general one can say that the data reproduce well the shape of the $d\sigma/dp_t^2$ for both the ϱ^0 and the π^+ production for the p_t^2 below 1 $(GeV/c)^2$. It should be mentioned that in models like this one, where the collision is supposed to be initiated by the interaction of wee partons, one cannot hope to reproduce the p_t spectra for the $p_t \geq 1$ GeV/c.

Our results for the ϱ^0 production are also here higher than the experimental data. This is closely connected with the question of $\langle n_{\varrho^0} \rangle$ discussed already above. In our opinion, it is therefore probably wiser to postpone the theoretical and phenomenological studies of the issue until the experimental discrepancies are resolved.

In Fig. 8 we present the predictions for the $d\sigma/dp_t^2$ of the inclusive production of the ϱ^0, π^+, π^- in π^+p collisions at 150 GeV/c. The results show the same general features as those obtained in the π^-p rection at the same energy.

3) We have used $\sigma_{inel} = 21.3$ mb. This is based on the data $\sigma_{tot} = 24.24 \pm 0.29$ (Fong et al. [9]), $\sigma_{tot} = 24.28 \pm 0.15$ mb (Caroll et al. [10]). Taking $\sigma_{el} = 3.03 \pm 0.3$ mb (Bogert et al. [11]) we get $\sigma_{inel} = 21.21 \pm 0.59$ mb, resp. 21.25 ± 0.45 mb. This is consistent with the value $\sigma_{inel} = 21.3$ mb given in Fig. 13 of the paper [8].

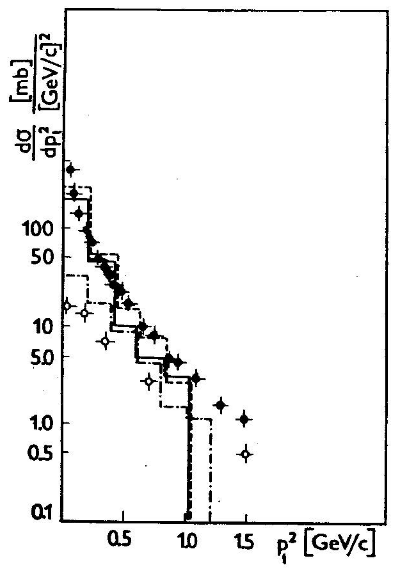

Fig. 7. Inclusive ϱ^0 and π^+ transverse momentum squared distribution from π^-p interaction. Symbols: experimental data (147 GeV/c): ○ – ϱ^0, ● – π^+; calculated values (150 GeV/c): —— π^+, – · – ϱ^+, - - - π^-. For comparison also the calculated π^- data are shown. Experimental data are taken from Fig. 58 in [15].

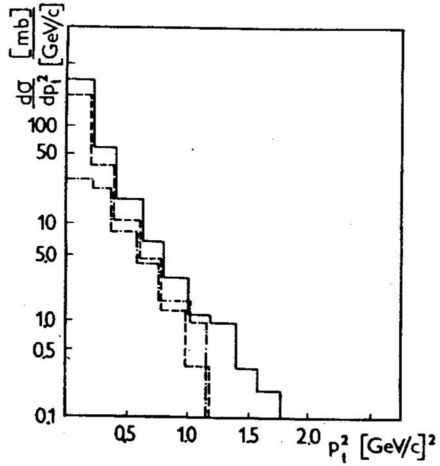

Fig. 8. Inclusive ϱ^0 and $\pi^\pm$ transverse momentum squared distributions from 150 GeV/c π^+p interaction (calculation). Symbols have the same meaning as in Fig. 7.

More detailed information is expected from the study of the rapidity spectra of particles produced in the π^-p collisions. In Fig. 9a we compare the data (see Figs. 50a, b in Whitmore's review [15]) with the results of our calculations for $\pi^-p \to \pi^+X$. The data are, in fact, from the 200 GeV/c interactions since, as far as we know, there are no data of this kind at 150 GeV/c. Our results, however, correspond to the latter energy. The inclusive π^+ production spectra are supposed to depend rather weakly on the incident energy (as ln s) and the present Monte Carlo program is rather computer time consuming, that is why we have not performed a similar calculation at 200 GeV/c. The part of the spectrum dictated by the phase spectra is reproduced correctly, there appear however marked differences in details.

The situation is somewhat better for the inclusive spectrum of $\pi^-p \to \pi^-X$ shown in Fig. 9b. The difference between the experimental and theoretical curves for the $d\sigma(\pi^-)/dy$ can perhaps be to some extent explained by the arguments proposed by Whitemore et al. [15] in order to explain the large asymmetry of $d\sigma(\pi^-)/dy$.

They assume that the bump in the region of large rapidities is caused by the leading cluster effect, namely that there is a "swarm" of particles separated from the rest by at least $\Delta y \approx 1$ and having the internal quantum numbers of π^-. Subtracting the contribution of such clusters the authors of Ref. [15] obtain the curve which is quite similar to the rapidity distribution of π^- in the pp collisions.

Our distribution is in fact quite similar to the one obtained by Whitmore et al. [15] after the subtraction of the leading cluster. This would be quite natural since the quark-parton model of Ref. [1, 2] does not contain contributions from diffractively produced clusters. We think, however, that the explanation given by Whitmore et al. is hardly correct since the production of the leading cluster then amounts to about 50 % of the inelastic cross section. This is rather unlikely. In order to understand this problem it will be necesary to compare the results of calculations with another set of data and to study the dependence of the rapidity spectra on the energy of the incoming particles.

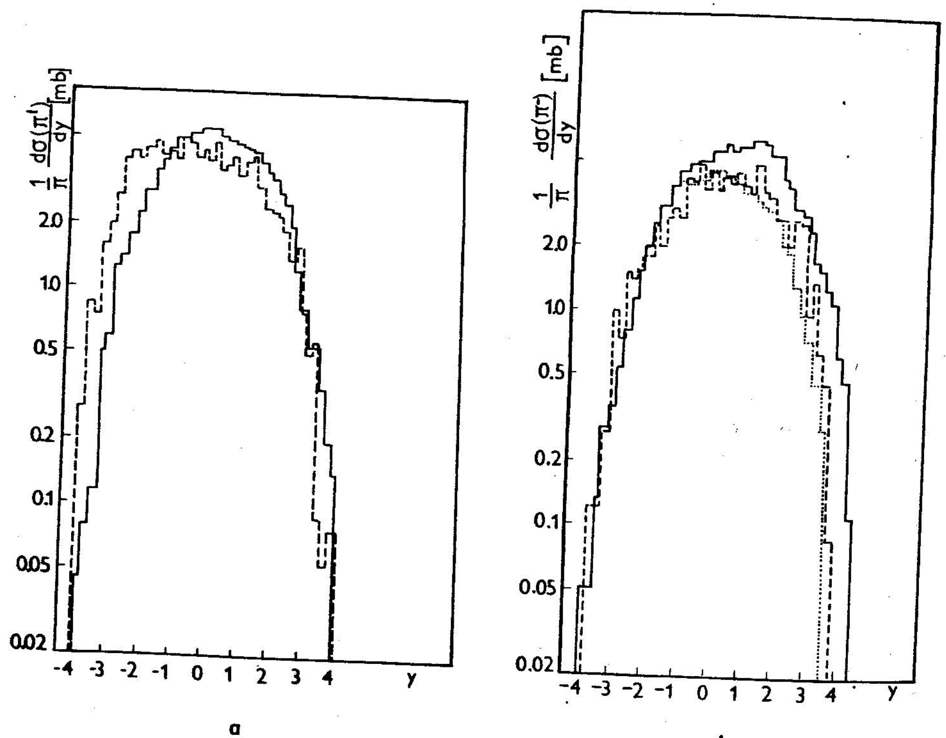

Fig. 9. CM rapidity distributions for (a) π^+ and (b) π^- produced in 200 GeV/c π^-p interaction and calculated for 150 GeV/c π^-p interaction. Symbols: — experimental (Figs. 50a, b in [15]), ···· experimental without the leading cluster (Fig 50b in [15]), ---- calculated.

It is also possible that the attempts at a more detailed agreement with the data will require modifications of the model. In particular we have here in mind the simplified assumptions in Eq. (1) concerning the matrix elements. A-part of the "coupling constant" G and the Kuti-Weisskopf factors $|x|^{1/2}$, the matrix elements are constants. Introducing an explicit dependence of matrix elements on the momenta of partons would change the parton distribution functions and thereby also the inclusive spectra.

Such studies will, however, require a lot of further work both theoretical and numerical (extensive computer calculations).

Rather interesting results were obtained in clacultions of the charge transfer across $y^* = 0$. The ΔQ is defined as a charge transferred from the beam to the target hemisphere, namely

$$\Delta Q = Q_\pi\,(initial) - Q_\pi\,(final) = -1 - Q_\pi\,(final)\,, \qquad (2)$$

where $Q_\pi\,(initial) = -1$ is the original charge present in the beam pion hemisphere and Q_π (final) is the charge of all the final state particles with positive c. m. rapidities (beam hemisphere).

The results of our calculations are compared with thedata [16] in Fig. 10. It is worth stressing that our calculations have qualitatively about the same asymmetry as the data. Also they reproduce well the average value of the charge transfer $\langle \Delta Q \rangle$. Our result is $\langle \Delta Q \rangle = -0.14 \pm 0.01$, whereas Levmann et al. [16] obtained, by using two different methods, the following values $\langle \Delta Q \rangle = -0.24 \pm 0.011$ (method A) and $\langle \Delta Q \rangle = -0.12 \pm 0.011$ (method B).

In Fig. 11 we present the predictions following from the model [1, 2] for the distribution of charge transfer between hemispheres for the π^+p collision at 150 GeV/c. The distribution has about the same qualitative shape as the one in π^-p reactions and the average value of the charge transfer is predicted to be $\langle \Delta Q \rangle = 0.05 \pm 0.005$.

Let us finally give the resulting values of the average charge in the beam hemisphere

$$\pi^-p \text{collision } \langle Q_\pi\,(\text{final}) \rangle = -1 - \langle \Delta Q \rangle = -0.86 \pm 0.02$$

$$\pi^+p \text{ collision } \langle Q_\pi\,(\text{final}) \rangle = 1 - \langle \Delta Q \rangle = +0.95 \pm 0.02.$$

The former quantity has naturally a smaller magnitude than the latter, since in the former case the charge transferred from the proton to the pion hemisphere decreases and in the latter enhances the $|\langle Q_\pi\,(final) \rangle|$.

Finally, we have studied the charge distribution in rapidity in the π^-p collisions at 150 GeV/c. Our results are compared with the data [17] in Fig. 12. The comparison indicates that the charge distribution in the "proton" hemisphere is

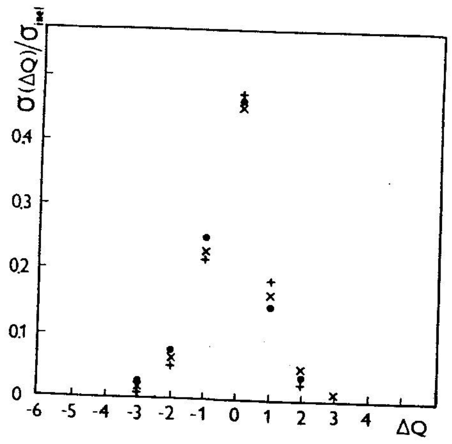

Fig. 10. Charge transfer cross section at 205 GeV/c π^-p interaction and results of present calculations for π^-p interaction at 150 GeV/c. Symbols: · method A [16], × method B [16], + the present calculation.

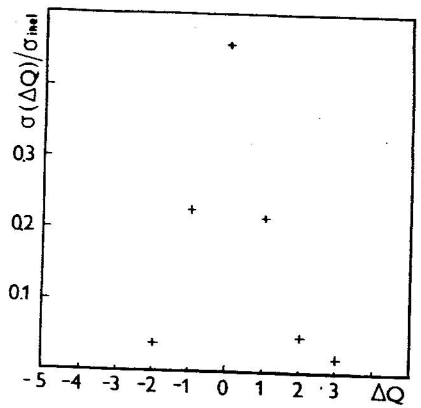

Fig. 11. Charge transfer cross section calculated for 150 GeV/c π^+p interaction.

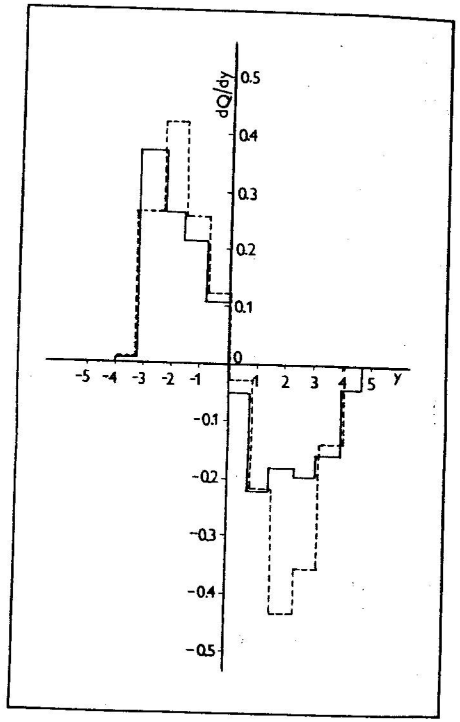

Fig. 12. Rapidity charge distributions as measured in 147 GeV/c π^-p interaction and calculated for 150 GeV/c π^-p interaction. Symbols: —— experimental [17], ---- calculated.

well reproduced by the model, whereas the calculated shape of dQ/dy in the "pion" hemisphere are narrower than the data.

A deeper understanding of this question requires a detailed study of the effects of misidentified protons on the charge distribution. The effects were discussed to some extent by Levman et al. [16].

IV. COMMENTS AND CONCLUSIONS

The present results corroborate further the conclusions made by the authors of Refs. [1, 2, 3] and based on the study of multiparticle production in proton-proton collisions.

The Monte Carlo quark-parton model [1, 2] reproduces well the qualitative features of the multiparticle production in πp collisions at 150 GeV/c. It has also to be stressed that in performing the comparison with the data, we have introduced no new free parameters. All the parameters used in the present calculation were taken directly from the preceding works [1, 2] on multiple production in pp collisions.

The fact that the larger mobility of the "pion" charge (as compared to the "proton" one) follows naturally from the model is most satisfactory.

In our opinion it si very desirable to study in more detail the multiple production in the πN collisions, in particular to extend the energy range to, say, 30—300 GeV/c and to study also the data on KN collisions.

ACKNOWLEDGEMENTS

The author would like to thank V. Černý, P. Lichard and J. Pišút for the permission to use their program and for numerous instructive and valuable discussions.

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Received February 2nd, 1978